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THE MINERAL QUALITY PROBLEM IN THE COLORADO RIVER BASIN. APPENDIX C. SALINITY CONTROL AND MANAGEMENT ASPECTS

Environmental Protection Agency
Denver, Colorado

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THE MINERAL QUALITY PROBLEM IN THE COLORADO RIVER BASIN

APPENDIX C

SALINITY CONTROL AND MANAGEMENT ASPECTS

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
REGIONS VIII AND IX

1971

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THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency was established by Reorganization Plan No. 3 of 1970 and became operative on December 2, 1970. The EPA consolidates in one agency Federal control programs involving air and water pollution, solid waste management, pesticides, radiation and noise. This report was prepared over a period of eight years by water program components of EPA and their predecessor agencies--the Federal Water Quality Administration, U.S. Department of Interior, April 1970 to December 1970; the Federal Water Pollution Control Administration, U.S. Department of Interior, October 1965 to April 1970; the Division of Water Supply and Pollution Control, U.S. Public Health Service, prior to October 1965. Throughout the report one or more of these agencies will be mentioned and should be considered as part of a single agency--in evolution.

PREFACE

The Colorado River Basin Water Quality Control Project was established as a result of recommendations made at the first session of a joint Federal-State "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries", held in January of 1960 under the authority of Section 8 of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.). This conference was called at the request of the States of Arizona, California, Colorado, Nevada, New Mexico, and Utah to consider all types of water pollution in the Colorado River Basin. The Project serves as the technical arm of the conference and provides the conferees with detailed information on water uses, the nature and extent of pollution problems and their effects on water users, and recommended measures for control of pollution in the Colorado River Basin.

The Project has carried out extensive field investigations along with detailed engineering and economic studies to accomplish the following objectives:

(1) Determine the location, magnitude, and causes of interstate pollution of the Colorado River and its tributaries.

(2) Determine and evaluate the nature and magnitude of the damages to water users caused by various types of pollution.

(3) Develop, evaluate, and recommend measures and programs for controlling or minimizing interstate water pollution problems.

In 1963, based upon recommendations of the conferees, the Project began detailed studies of the mineral quality problem in the Colorado River Basin. Mineral quality, commonly known as salinity, is a complex Basin-wide problem that is becoming increasingly important to users of Colorado River water. Due to the nature, extent, and impact of the salinity problem, the Project extended certain of its activities over the entire Colorado River Basin and the Southern California water service area.

The more significant findings and data from the Project's salinity studies and related pertinent information are summarized in the report entitled, "The Mineral Quality Problem in the Colorado River Basin". Detailed information pertaining to the methodology and findings of the Project's salinity studies are presented in three appendices to that report - Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality", Appendix B, "Physical and Economic Impacts", and Appendix C, "Salinity Control and Management Aspects".

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CHAPTER I INTRODUCTION

Salinity is one of the most serious water quality problems in the Colorado River Basin. Like many streams in the arid West, the Colorado River displays a progressive increase in salinity (total dissolved solids)[1/] between its headwaters and its mouth. Salinity concentrations in the Lower Colorado River below Lees Ferry, Arizona are approaching critical levels for municipal, industrial, and agricultural water use. In the face of this present situation, planned and proposed water resource developments, primarily in the Upper Basin, will cause further increases in salinity concentrations in the Lower Colorado River.

As a part of its investigations of interstate pollution problems, the Colorado River Basin Water Quality Control Project (Project) has carried out activities since 1963 directed toward three primary objectives related to the salinity problem. These objectives are:

(1) To assess the nature and magnitude of the salinity buildup in the main stem of the Colorado River and its tributaries,

(2) To evaluate the net basinwide economic benefits associated with various degrees of control, and

---

1/ The terms "salinity" and "total dissolved solids" are used synonymously throughout this Appendix.

(3) To investigate and evaluate feasible methods of controlling and minimizing salinity concentrations and loads in the river.

Project activities concerned with the first objective are discussed in detail in Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality." To provide the basis for evaluating the economic benefits of salinity control, the second objective, detailed studies of the physical and economic effects of salinity on water use in the Colorado River Basin were carried out. The results of these studies are discussed in Appendix B, "Physical and Economic Impacts." This appendix summarized the present status of knowledge with respect to the second and third objectives. Results of activities completed to date are sufficient to achieve these objectives only provisionally. Most of the evaluations presented herein are based on preliminary data not on final results. Activities are continuing which will improve the store of salinity control knowledge and which will result in refinement and improvement of the information presented. This report can thus be considered an interim summary of the "state-of-the-art" with respect to salinity control and Management for the Colorado River Basin.

Closely related to the salinity control studies described herein were the efforts to establish water quality standards for the interstate waters of the Colorado River system as required by the Water Quality Act of 1965. Early in the process of

establishing standards, it became apparent that available information on the technical aspects of management and control of salinity was not adequate to develop equitable, workable and enforceable salinity standards. The water quality standards subsequently developed by the states and approved by the Secretary of the Interior did not include numerical salinity standards. However, the Secretary stated that it would be the intention of the Department of the Interior and basin states to pursue active programs to lay the foundation for setting numerical criteria with emphasis on the demonstration of salinity control measures and ways to revise the legal and institutional constraints that could impede implementation and enforcement. The Project's activities thus form a major link in Department of the Interior's efforts to provide the basis for establishing suitable salinity standards. Activities related to salinity standards are summarized in Chapter II.

A wide range of technical possibilities for salinity control were identified and their potential feasibility for application in the Colorado River Basin evaluated. Present knowledge of many of these control measures is quite limited before actual project application can be anticipated. Present information is considered adequate, however, to provide a basis for preliminary estimates of the potential for salinity control in the Colorado River Basin. The various salinity control measures evaluated are discussed in Chapter III.

A number of technical investigations as well as research

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and demonstration projects directed towards improving salinity control and management knowledge have been undertaken by other institutions and agencies with financial support from the Federal Water Quality Administration. These activities have contributed to the third primary study objective. The present status of these activities is discussed in Chapter IV.

To provide the basis for determining the potential feasibility of basinwide salinity control, a total of eight alternative control programs were formulated. Cost estimates were prepared for these programs which included three salt load reduction programs, four flow augmentation programs and a water supply treatment program, and the relative costs and water quality effects were compared. The phased implementation of a salt load reduction program was selected as the least cost alternative and costs of the program were utilized to evaluate the economic feasibility of various levels of salinity control.

A number of alternative economic or water quality objectives were identified which a basinwide control program could seek to achieve. The water quality and economic effects associated with each of these objectives for the least cost program were evaluated. The distribution of salinity costs associated with these objectives were evaluated and are discussed in Chapter V.

The Project's investigations comprise essentially a reconnaissance level analysis of the overall salinity problem and provide a preliminary assessment of the potential for achieving a measurable degree of salinity management. It is clear, however, that further investigation and demonstration

of salinity control technology will be required before a basinwide salinity control plan can be formulated and implemented. Also, a number of legal and institutional factors must be analyzed and modified where practical before implementation of a basinwide plan can be assured.

CHAPTER II. MINERAL QUALITY STANDARDS

The salinity problem in the Colorado River Basin (see figure 1) was brought into sharp focus by the passage of the Water Quality Act of 1965.(1) Under this Act, the states were required to adopt water quality standards for their interstate waters along with a plan for implementing and enforcing standards by June 30, 1967. Early in the standards-setting process, representatives of the water pollution control agencies for the seven Basin States recognized that it would be highly desirable to have agreement on certain principles and factors to be used in formulating consistent State water quality standards for the interstate waters of the Colorado River system. A Technical Water Quality Standards Committee was therefore formed for this purpose. It consisted of one representative from the water pollution control agency for each of the seven Basin States. Between August 1966 and December 1967, the Committee held a number of meetings for the purpose of reaching agreement on the principles and factors to be used in developing consistent State water quality standards for the interstate waters of the Colorado River system. At the outset, members of the Technical Committee recognized that, because of legal and institutional constraints combined with lack of technical knowledge on its control and management, salinity would be a most difficult problem to resolve in their standards-setting process.

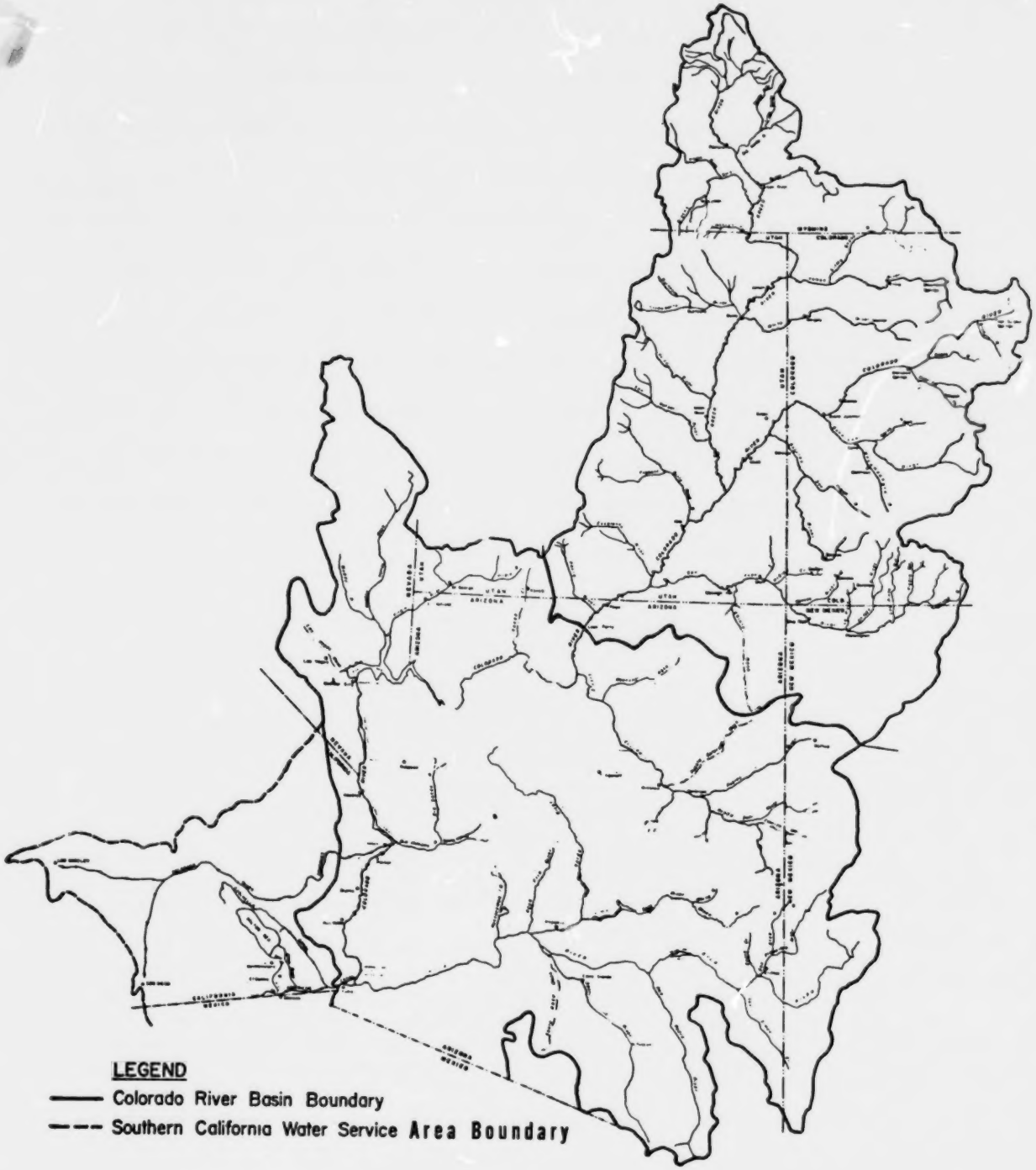

Figure 1 Colorado River Basin and Southern California Water Service Area

At the fourth meeting held in Phoenix, Arizona, on January 13, 1967, the Technical Committee reached final agreement on "Guidelines for Formulating Quality Standards for the Interstate Waters of the Colorado River System."(2) A significant point covered under "General Considerations" program for establishing within two years the numerical criteria for such specific chemical constituents as chlorides, sulfates, sodium and boron. Representatives of the water pollution control agencies of the seven Colorado River Basin States met in Denver, Colorado, on November 15, 1967 to consider FWPCA position on numerical criteria for total dissolved solids. By unanimous vote, the representatives of the seven Basin States (Conferees) adopted a "Resolution Relative to Numerical Standards for Salinity of the Colorado River System."(3) It was resolved:

(1) "That the Conferees do not believe it is appropriate that a standard of 1,000 mg/l or any other definite number for TDS at Imperial Dam be set by the basin states or the Secretary of the Interior at this time.

(2) "That the Conferees urge the completion of water quality reports of the Federal agencies at the earliest practicable date, and that thereafter the basin states and Federal agencies again consider the setting of salinity standards for the Colorado River system.

(3) "That the Conferees hereby urge the FWPCA to consider the approval of the water quality standards of the seven Colorado River Basin states conditioned upon ultimate establishment of acceptable numerical salinity standards after completion and consideration of FWPCA and Bureau of Reclamation reports presently underway."

The Chairman was instructed to transmit copies of the resolution to the Secretary, Department of the Interior; Commissioner, FWPCA; and Director, Southwest Region, FWPCA. It was also agreed that each Conferee would attempt by appropriate

means to achieve support of the resolution by the Governor of his State and encourage transmission of the resolution to the Congressional delegation.

The Secretary of Interior expressed his views concerning salinity standards for the Colorado River in his statement of January 30, 1968 to the House Subcommittee on Irrigation and Reclamation(4) (House Document 90-5, Colorado River Basin Project, Part II, pp. 705-706). His remarks on this matter include the following statement:

> "The Colorado River is the only major river of the world that is virtually completely controlled. With the existing system of large storage reservoirs it is possible to plan, for all practical purposes, on complete utilization of the river's runoff with no utilizable water escaping to the sea. This means that the limited water supply in the Colorado River Basin must be used and reused and then used again for a wide variety of purposes. In this complete utilization of runoff, the Colorado Basin is unique.
>
> "The River is unique also with respect to the number and extent of the institutional constraints on the division and use of the Basin's water which include an international treaty, two interstate water compacts, Supreme Court decisions, Indian water rights, State water laws, and Federal law.
>
> "These two aspects, in turn, make the problem of setting numerical mineral quality standards for the Colorado River not only unique but extremely complicated. Before discussing this problem further, I would like to state that salinity standards will not be established until we have sufficient information to assure that such standards will be equitable, workable, and enforceable.
>
> "The principal water uses in the Basin include irrigated agriculture, municipal and industrial water supply, fish and aquatic life, and recreation. Salinity in the Colorado River has no significant effect on instream or nonconsumptive water uses such as hydroelectric power generation and water-oriented recreation. However, ever-increasing levels of salinity do have an adverse impact on the consumptive uses of water for both irrigated agriculture and municipal and industrial water supply.

> "Further development and depletion of water allocated to the Upper Basin States will raise the salinity of water downstream.
>
> "Salinity standards must be so framed that they will not impede the growing economy of the Colorado River Basin and yet not permit unwarranted degradation of water quality. This is the hard dilemma which is the core of the problem of establishing equitable salinity standards.
>
> "A decision not to set salinity standards at this time does not and will not preclude getting started with programs to study and demonstrate the feasibility of controlling and alleviating the Basin's salinity problem."

The Secretary also discussed some promising methods of attaching the salinity problem. He concluded his remarks by stating: "Although the salinity problems of the Colorado River are difficult, I am confident that they can and will be resolved."

In letters dated February 2, 1968, to Governors of several Basin States, the Secretary of Interior also made the following statements concerning salinity standards:

> "After consideration of all the factors involved, I have decided that salinity standards should not be established until such time as we have sufficient information to be reasonably certain that such standards will be equitable, workable, and enforceable. Arriving at this decision at this time does not and will not preclude initiating of programs to study and demonstrate the feasibility of controlling and alleviating the Basin's salinity problem."

In a letter to the Chairman, Technical Water Quality Standards Committee for Colorado River Basin States, dated February 12, 1968, the Assistant Secretary for Water Pollution Control, Department of the Interior, made the following comments regarding the Secretary's position on the establishment of salinity standards for the Colorado River:

> "It is the intention of the Secretary that the Department of the Interior and the states pursue active programs to

> lay the foundation for setting numerical criteria at some future time. These programs should focus on devising and demonstrating salinity control measures and finding ways to revise the legal and institutional constraints that could impede the implementation and enforcement of salinity standards."

The seven Basin States' water quality standards for the interstate waters of the Colorado River system, which contained no specific numerical criteria for salinity, were subsequently approved by the Secretary of Interior. No further formal action has been taken by the States toward adopting mineral quality standards for the Colorado River.

CHAPTER III. TECHNICAL POSSIBILITIES FOR SALINITY CONTROL

Salinity increases result from many diverse factors. However, two basic process -- salt loading and the salt concentrating effects of consumptive water use -- are the primary causes of salinity increases. Two types of salinity control measures -- water-phase and salt-phase methods -- may be employed to control or minimize these processes. Water-phase measures are those employed to reduce salinity concentrations by increasing the volume of water available for dilution of a given salt burden. This can be accomplished by conserving the water supply presently available in the Basin or by increasing the Basin supply through importation or other augmentation measures such as weather modification. Salt-phase measures function to reduce salinity concentrations by reducing the salt load discharged to the river system. Salt load reductions can be achieved in a variety of ways including desalination or impoundment and evaporation of highly mineralized spring flows, modification of irrigation practices and improvement of irrigation facilities to minimize salt pickup by return flows, and the subsurface injection of highly saline industrial wastes.

A number of salinity control measures have been identified which have technical merit and which may be applicable to salinity problems in the Colorado River Basin. These measures are outlined in Table 1.

All of the salinity control measures listed in Table 1

Table 1. Technical Possibilities for Salinity Control

I. Measures for Increasing Water Supply

A. Water Conservation Measures

1. Increased Watershed Runoff
2. Suppression of Evaporation
3. Phreatophyte Control
4. Optimized Water Utilization for Irrigation
   a. Reduced Consumptive Use
   b. Improved Irrigation Efficiency
5. Water Reuse

B. Water Augmentation Measures

1. Weather Modification
2. Water Importation
   a. Fresh Water Sources
   b. Demineralized Sea Water

II. Measures for Reducing Salt Loading

A. Control of Natural Sources

1. Natural Discrete Sources
   a. Evaporation of Discharge
   b. Injection into Deep Geological Formations
   c. Desalination
   d. Suppression of Discharge
   e. Reduction of Recharge
2. Natural Diffuse Sources
   a. Surface Diversions
   b. Reduced Groundwater Recharge
   c. Reduced Sediment Production

B. Control of Man-Made Sources

1. Municipal and Industrial Sources
   a. Evaporation
   b. Injection into Deep Geological Formations
   c. Desalination
2. Irrigation Return Flows
   a. Proper Land Selection
   b. Canal Lining
   c. Improved Irrigation Efficiency
   d. Proper Drainage
   e. Treatment or Disposal of Return Flows

have been given consideration in the search for the most practical means of achieving basinwide salinity management. Technical investigation, research and demonstration project activities completed to date have indicated that some of the methods considered are not economically feasible and other measures may not be practical due to institutional and legal constraints or other factors. The salinity control potential of water conservation measures has not been evaluated quantitatively as present legal and institutional constraints would appear to preclude any practical application of such measures at this time. Such measures are discussed in qualitative terms in this chapter however, as a means of identifying their potential should existing constraints be modified in the future.

Implementation of water augmentation measures to increase the Basin water supply, would also provide significant salinity control benefits. The salinity control potential of several augmentation measures has been evaluated in detail. These measures are discussed qualitatively in this Chapter and quantitatively in Chapter V.

A large number of salt load reduction measures were given consideration; however, only a few are considered to be economically feasible at this time. All of the measures considered are discussed qualitatively in this Chapter as a means of comparison. Those measures which appear to be practical or economically feasible include desalination or impoundment

and evaporation of highly mineralized flows from discrete sources including mineral springs, diversion of certain stream sections, and reduction of salt pickup by irrigation return flows by lining canals, improving irrigation efficiency and installation of subsurface drains. These measures are discussed quantitatively in Chapter V.

MEASURES FOR INCREASING WATER SUPPLY

Although highly variable from year to year, the Colorado River Basin receives a relatively fixed total water supply from atomspheric precipitation. Much of this supply is depleted by evapotranspiration and out-of-basin diversions with only a small fraction leaving the Basin as discharge of the Colorado River. Under virgin conditions, evapotranspiration occurred from native vegetation, from natural water courses, and from land and snow surfaces.

Development of the Basin's water resources has increased water losses in several ways. Construction of large reservoirs and canal systems has increased evaporation from water courses. The development of irrigated areas has increased the vegetation present in the Basin and accompanying transpiration losses. Irrigation and reservoir construction have also raised the groundwater table in many areas which has been accompanied by increased growth of native vegetation and increased evaporation from the land surface. The amount of water diverted out of the Basin has also increased over the years. Together, these losses have reduced the water supply remaining to carry

mineral salts out of the Basin and have contributed to the increases in average salinity concentrations above those concentrations existing under virgin conditions.

Man's activities have also increased the salt burden carried by the river system. This increased salt burden also contributes to the increases in salinity concentrations above virgin conditions but to a lesser degree than the decrease in water supply.

Much time and effort has been directed toward understanding the natural processes which make up the hydrologic cycle. As a result, a number of techniques have been developed for minimizing evapotranspiration. Along with water reuse, these techniques can be classified as water conservation measures.

Study of the hydrologic cycle has also yielded potential methodology for modifying precipitation. Weather modification and water importation are two activities which can be classified as water augmentation measures. The technical merits of water conservation and augmentation measures from the view point of salinity control are discussed in the following sections.

Water Conservation Measures

Water may be conserved at a number of points as it passes through the various phases of the hydrological cycle. Conservation measures may be applied in the headwaters, in the river and reservoir system, and at the point of consumptive use.

Increases Watershed Runoff. Man has attempted to modify the natural vegetative cover of watersheds in a manner which would

reduce the rate of runoff following precipitation. Such modification has produced several effects including reduced flood flows, reduced sediment production, and higher base flows during low-flow periods. This latter effect contributed to the belief that holding precipitation on the watershed increased the watershed yield.

From a salinity control viewpoint, the present practices of watershed management may be detrimental. We now know that holding precipitation on the watershed increases evapotranspiration and decreases watershed yield. Reduced runoff rates also increase the opportunity for precipitation to dissolve salts from the soil and groundwater aquifer and salt pickup rates from the watershed may be increased. Increasing the rate of runoff from a watershed may thus produce lower salinity concentrations, both in the water supply derived from the watershed and at other downstream locations. Large downstream reservoirs are available to regulate this increased runoff for downstream use.

The U. S. Forest Service and various state agencies are experimenting with forest management practices as a means of increasing watershed yields and rates of runoff. Some of the practices under study include forest cutting, logging and slash disposal, conversion of bushland to forest, burning of underbrush, and grazing.

A large portion of Colorado River streamflow originates in mountain forest areas. Increasing the water yield and

reducing the salt contribution of forest areas could thus have a major impact on salinity problems. Increasing rates of runoff could produce adverse effects however, such as increased sediment concentrations in streams, reduced low-flow volumes with accompanying warmer water temperatures, and degraded fish and wildlife habitat. Studies, conducted jointly by appropriate State and Federal agencies, are needed to determine if watershed management techniques can be modified to improve the quantity and quality of watershed yields without causing the adverse effects previously described. Investigations of techniques for increasing the rate of runoff from non-forested areas, such as the construction of impervious catchment areas and the treatment of solid surfaces are also needed. No estimates are currently available of the increases in watershed yields or decreases in salinity concentrations that could be achieved by application fo such measures.

Suppression of Evaporation. Water losses by direct evaporation from the surface of reservoirs, lakes, streams, and canals are large. Evaporation losses from large, mainstem reservoirs alone are presently estimated to exceed 1 million acre-feet annually under normal operating conditions. Such losses increase salinity concentrations by reducing the water available for dilution of a given salt burden.

Since evaporation losses are directly related to water surface area, one obvious control method for reservoirs is to maintain the water surface at the minimum area practicable.

However, operating requirements place serious constraints upon maintenance of a minimum area. Reservoirs in the Colorado River Basin are also relatively deep with respect to their surface area and significant reductions in storage produce relatively small reductions in surface area.

A significant amount of research effort has been devoted to development of chemical covers for reservoirs such as monomolecular films. Such films have proven effective in suppressing evaporation but their cost and tendency to be broken up rapidly by wind action or biological activity reduce their practicality.

No practical methods for reducing evaporation from flowing streams have been developed. Evaporation losses from irrigation conveyance systems can be reduced by covering canals and by using pipe distribution systems. The use of pipe systems also reduces seepage losses; and, in some cases, the pickup of salt by return flows is decreased. The feasibility of installing pipe distribution systems is dependent upon a number of factors, and construction cannot be justified on the basis of evaporation reduction alone.

The magnitude of evaporation losses is such that research should be continued to develop economical methods of suppressing evaporation. The salinity control effects of enclosed distribution systems should also receive further study to determine if additional benefits would justify the installation of effective evaporation control devices.

Phreatophyte Control. Phreatophytes are non-beneficial plants with a high rate of consumptive water use. Phreatophytes are found in areas where the groundwater table is near the surface allowing the plants to derive their water supply from groundwater. Common locations are along the banks of streams and reservoirs or on wasteland adjacent to irrigated areas. Based on present surveys of phreatophyte acreages, these losses are estimated to total several hundred thousand acre-feet annually. Such losses contribute significantly to increases in salinity concentrations.

Phreatophytes may be controlled by lowering the water table below the depth of root penetration and by removing or destroying the plants by mechanical or chemical means. In most cases where the water table is now lowered, controls must be continued to prevent regrowth. Revegetation of the cleared areas with beneficial crops or with plants having a lower consumptive water use may be a satisfactory method of long-range control.

Some phreatophytes provide erosion control and shelters for livestock. Other phreatophytes provide wildlife habitat which may complement recreational activity. The feasibility of removing such growths would be dependent upon the practicality of providing suitable substitute vegetation with lesser consumptive water use.

Optimized Water Utilization for Irrigation. Irrigation has been practiced in the Basin since the latter part of the nineteenth century. Irrigation practices in many areas have changed little since the traditional methods developed by the early

irrigators. Prior to the construction of storage reservoirs and modern canal systems, irrigation supplies were obtained by direct diversion from flowing streams. Streamflow was high during the spring snowmelt but dwindled to very low levels during late summer. A heavy application of irrigation water was made in the spring with the hope that storage in the soil would offset a deficiency of supply in the latter part of the growing season. Such application methods resulted in poor irrigation efficiencies and excessive water diversions.

With the construction of storage reservoirs to even out the seasonal supply, irrigators were slow to adopt more efficient irrigation practices. In many cases water rights were based on the excessive diversions formerly made. Irrigators were reluctant to reduce water diversions as part of their water rights could be lost. Thus, in many areas, irrigation efficiencies are less than optimal and significant water conservation could be achieved by optimization of water utilization.

Water use for irrigation can be minimized by reducing consumptive use through proper selection of land and crops or by improving irrigation efficiency through proper irrigation management. These conservation measures are discussed in the following sections.

Reduced Consumptive Use. The total water consumptively used by a given irrigated area is dependent upon the consumptive use per acre of growing crops, the total irrigated acreage, and the volume of non-beneficial losses such as evapotranspiration

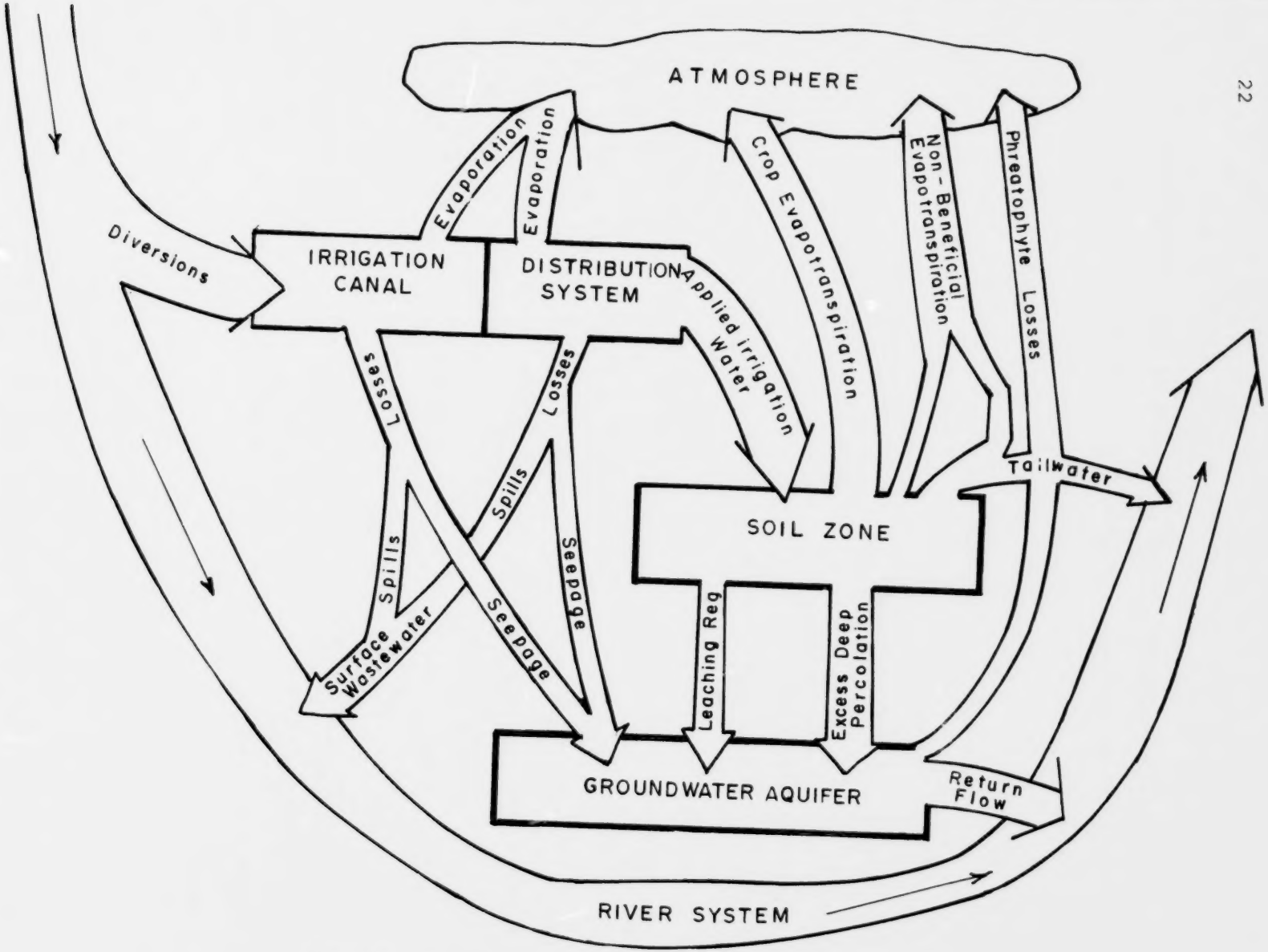

Figure 2. Schematic Drawing of Irrigation Cycle

by phreatophytes. Reduction of any one of these factors will conserve water.

Different crops have different water requirements. Consumptive use of water could be decreased by growing crops that use less water per unit of food or fiber produced. Thus, water conservation could be effected by promoting the raising of the most efficient water-using crops of equal economic value. The development of new crop varities that are more efficient in water utilization would achieve additional conservation. The water conservation that could be achieved by crop modification would be small however, in relation to the potential conservation that could be achieved by increased irrigation efficiency.

A number of irrigated farms scattered throughout the Basin provide only a marginal economic return to their owners. These farms may be limited to inefficient operation by poor soils, poor drainage, marginal or inadequate water supply, or other factors. Eliminating the irrigation of farms that are not economically efficient would reduce irrigated acreage and consumptive use. Factors that limit the practicality of such action include the difficulty in evaluating which farms should stop irrigating, the problems in transferring water rights and possible relocation of farm owners or tenants.

Significant quantities of water, in the form of surface runoff and excessive return flows, are wasted by inefficient irrigation practices. Some of this waste water may support substantial consumptive use by non-beneficial vegetation located on

non-irrigated land. Improvement of irrigation efficiency would reduce the volume of water wasted and would help reduce such non-beneficial losses. Methods of improving irrigation efficiency are discussed in the following section.

Improved Irrigation Efficiency. In normal practice, the volume of water supplied to an irrigated area is much larger than the volume of water consumptively used by growing crops. The ratio of the volume consumed to the volume supplied is known as the irrigation efficiency and may be determined for a number of different points in an irrigation system such as the supply reservoir or the farm headgate. Improving irrigation efficiency reduces the gross supply that must be provided for a given irrigated area and may reduce consumptive use in some cases as previously discussed.

Unnecessary water losses occur at a number of points in the irrigation cycle. These losses are shown schematically in Figure 2. Efficient irrigation requires the application of only enough water to meet the consumptive use requirement of crops plus some excess flow to leach accumulated salts from the root zone (termed the leaching requirement). Efficiency can thus be improved by reducing all other water losses.

Land characteristics such as soil type, soil permeability, land slope, surface drainage patterns, and depth to the water table or impermeable barrier are limiting factors in obtaining high irrigation efficiencies. Thus, proper selection of new land for irrigation can eliminate those areas that would require

excessive water supplies for crop production. Classification of existing irrigated areas with respect to land characteristics would allow identification of those areas which possibly should be removed from irrigation because of serious limitations on obtainable irrigation efficiencies.

In many systems, large volumes of water are lost by seepage from canals and distribution systems between the point of diversion from the stream or the storage reservoir and the farm. Reduction of seepage losses by lining canals and pipe distribution systems can substantially increase overall irrigation efficiency.

Perhaps the most significant factor affecting farm irrigation efficiencies is the management of both the timing and method of application of irrigation water. By timing the application to meet crop requirements and by selection of the method of application to match crop and land characteristics, high efficiencies can be obtained. It is estimated that improved irrigation methods and practices could reduce the farm irrigation requirement by as much as 30 percent.

Construction of storage and equalizing reservoirs for irrigated areas obtaining irrigation supplies by direct diversion from uncontrolled streams provide major improvements in farm efficiencies in these areas by allowing a change to a demand system of irrigation. Under such a system, the timing of irrigation applications can be based on crop requirements rather than on the seasonal availability of a water supply. In one

irrigated area in Utah, overall irrigation efficiencies increased by an estimated 20 percent following completion of a storage reservoir and inauguration of the demand system of irrigation.(5)

Proper selection of methods of applying irrigation water can also significantly improve farm efficiencies. Flood irrigation methods, which are commonly used in the Upper Basin at present, result in poor irrigation efficiencies in most cases. Use of such methods as border strips, furrows, corrugates, and sprinkler systems can produce field application efficiencies of over 50 percent.

A program to educate and assist irrigators in the selection of methods of application and proper timing of irrigation could significantly increase farm efficiencies. Consolidation of irrigation companies, canal companies, irrigation districts, drainage districts, and private ditch companies or users into one unit for an irrigated area would provide an organization for establishing an educational and assistance program and would also allow more efficient distribution of the available irrigation water. A single entity controlling all of the irrigation and drainage systems in an area could promote more efficient irrigation by establishing rules for determining irrigation needs, economic incentives for installing more efficient irrigating methods or systems and practices and by establishing penalties for misuse of irrigation water. This would require legal and institutional changes, however, and might be difficult to implement in many cases.

Water Reuse

By utilizing the waste water or return flow from an industry, municipality, irrigated area or other water uses to supply the water requirements of additional users, the gross volume of water diverted from a river system to supply all users may be reduced. In the case of a single water user, recycling of all or a part of the waste water can reduce gross water requirements. In the extreme case, wastewater discharge can be eliminated and gross diversions reduced to consumptive use requirements.

The economic feasibility of water reuse is dependent upon the relative costs of sequential water use or of treating wastewater for reuse versus the costs of providing and treating a larger raw water supply. The technical feasibility is dependent upon the availability of treatment methods, such as desalination, capable of producing suitable quality water from wastewater, or the presence of suitable industries, etc., with water quality requirements which will allow sequential water use.

Salinity Control Effects of Water Conservation

Application of water conservation measures should result in a temporary increase in the available water supply of the Basin. However, the long-term effects on supply and the availability of any supply increase for salinity control are not clear.

Reduction of consumptive use by irrigation, by phreatophytes, and in the headwaters area would increase the available water supply. In areas where the present supply is fully utilized,

availability of additional water would probably result in new land being placed under irrigation to utilize any surplus water. This action is encouraged by the appropriate water right procedures which prevail in many state water laws. Thus, the long-term effect of such water conservation could be no net change in the water supply available for salinity control.

Reduction of diversion requirements by water reuse or improved irrigation efficiency could have a slightly different effect on available water supply. The immediate result would be an increase in the supply available at the point of diversion. This surplus water would probably be utilized as previously discussed. Increasing the irrigated acreage would increase consumptive use. Thus, the long-term effect of such conservation measures might actually be a decrease in water supply leaving a subbasin. It is doubtful if any increased supply of water available for salinity control would result.

Reduction of reservoir evaporation losses could potentially increase the available water supply for salinity control as such savings would be produced below most Upper Basin use points. Long-term releases from the Upper Basin will probably eventuallly be held to compact allotments. Thus, conserved water would probably be utilized to meet Lower Basin delivery requirements allowing increased consumptive use in the Upper Basin.

The application of conservation measures in areas receiving water exports could potentially increase available supply by decreasing export requirements. However, any increased supply would probably be beneficial used as previously discussed resulting in no increase in the supply available for salinity

control.

In summary, under present legal constraints and traditional patterns of water utilization, the application of water conservation measures would produce few benefits as a direct result of increased water supply available for salinity control. Such measures may be significantly beneficial in reducing salt loading as discussed later in this chapter. Also, if legal constraints were modified to make only a portion of the conserved water available for salinity control, significant benefits could result.

Water Augmentation Measures

The actual quantity of water available for use in the Colorado River Basin and its allocation among water users has been the subject of much controversy. It is now apparent that a water shortage will exist in the Basin if the water resource developments proposed by various local, state, and federal agencies are carried to completion. To alleviate this shortage, a number of water augmentation measures have been investigated. These measures include weather modification to increase Basin precipitation and various schemes to import high quality water from other river basins or from the ocean following desalination. A number of potential water augmentation measures are discussed in the following sections.

Weather Modification. Increasing precipitation and watershed yield by weather modification is a relatively new concept. Consequently, operations in this field have not progressed significantly beyond the pilot stage. Pilot scale activities

conducted for several years in several states by a number of agencies including the Bureau of Reclamation have shown the technical feasibility of increasing watershed runoff by as much as ten to twenty percent.(6)

Research has been initiated by the Bureau of Reclamation to investigate the feasibility of augmenting Colorado River flow by weather modification. A five-year pilot program of weather modification in the Upper Basin was initiated in September 1968. Seeding of target areas will begin during the 1970-1971 winter season.

Preliminary estimates indicate that an annual watershed yield increase of as much as 1.87 million acre-feet might be obtained by a full-scale, basinwide weather modification program.(6) Costs are estimated to total less than $1.50 per acre-foot of increased yield. Results of the pilot program will allow these estimates to be verified and refined.

A full-scale program would probably concentrate on increasing snowfall in the high mountain areas of the Upper Basin. Since runoff from these areas is generally low in salinity, the increased yield would probably be low in salinity also, with significant salinity control benefits.

Water Importation. Traditionally, man has devised schemes for transporting water from areas of excess supply to areas of need whenever water shortages have developed. Thus, the impending water shortage in the Colorado River Basin has spawned a number of diverse and imaginative proposal for augmenting basin

supply by importation of high quality water from various sources outside the basin. At least six major projects which would import water from other basins have been proposed in the past. In most cases these proposals envisage tapping rivers in the Pacific Northwest which, at present, have surplus water available.

In addition, several international water resource development schemes have been proposed which would integrate a number of river systems in Canada and the United States. Surplus Canadian water could be diverted southward by such development to a number of water-short areas including the Colorado River Basin.

Water imported from most of the sources considered by these schemes would be high quality with relatively low salinity concentrations (less than 300 mg/l). The introduction of large quantities of this low salinity water could substantially reduce salinity concentrations at a number of locations in the Basin. The degree and location of resulting salinity control is dependent upon the locations of both the point of importation into the Basin and the point of consumptive use. Significant quantities of salt will be imported along with the water thus increasing the salt burden carried by the river system. If water were imported into the Upper Basin and significant quantities consumptively used at that location, the salt load reaching the Lower Colorado River would be increased and the salinity contol effects of flow augmentation would be less than if the entire volume of imported water were allowed to reach the

Lower Basin. The proposed location and magnitude of water imports and associated consumptive use must be carefully evaluated for each importation scheme to insure that the salinity control effects of water importation are maximized.

Another potential source of high quality water for importation into the basin is demineralized sea water. Desalination techniques have steadily improved in recent years with concurrent reductions in unit costs of demineralized water. At present, desalination is not competitive with alternative sources of fresh water. It is anticipated that unit costs of demineralized water will continue to decrease as a result of continued research and development in this field. Thus, desalination should receive further consideration as a source of imported water.

The Gulf of California and Pacific Ocean are in relatively close proximity to the Lower Colorado River and to areas utilizing large amounts of Colorado River water. Demineralized sea water from these two sources could potentially be utilized to augment the Basin supply directly or to indirectly increase the supply available for use in the Basin by exchange of water outside the Basin. By exchanging demineralized water for Colorado River water now diverted out of the Basin to such areas in Southern California, out-of-basin diversions could be decreased resulting in an increase in the supply available for use in the Lower Colorado River Basin. If the demineralized water were imported into the Basin to a point such as Hoover Dam, significant reductions in salinity concentrations in the Lower Colorado River

would result. Decreasing out-of-basin diversions by exchange of water would produce little effect on salinity concentrations in the Lower Colorado River. Significant improvement in the quality of the water supplied to the area receiving the demineralized exchange supply would result however.

A proposed large-scale desalination plant located near Los Angeles has received serious consideration as a source of supplemental water supply for that metropolitan area. Depending upon the timing of the construction of this facility, this source could possibly be utilized to supply water in exchange for present Colorado River diversions.

A reconnaissance study completed by the Bureau of Reclamation in January 1968, determined that it may be technically feasible to import demineralized sea water from a desalination plant, located between Los Angeles and San Diego on the Pacific Ocean, to augment the flow of the Colorado River at Hoover Dam.(7) Staged development with flow augmentation increasing from one-million acre-feet in 1990 to two-million acre-feet in 2010 was evaluated. A large aqueduct and numerous pumping plants would be required to convey the demineralized water to Lake Mead. Thus, the cost of such imported water would be high. This source could also be utilized to provide exchange water to the Southern California area. An exchange scheme would eliminate the need for the lengthy aqueduct with a significant reduction in average water costs. However, no salinity control in the Lower Colorado River would result.

A related study of a potential desalination plant located on the Gulf of California in Mexico has been conducted jointly by the United States and Mexico under the chairmanship of the International Atomic Energy Agency.(80) This study demonstrated that it would be technically feasible to provide a supplemental water supply for the Lower Basin from such a source.

MEASURES FOR REDUCING SALT LOADING

Salt is discharged to the Colorado River system from a variety of sources, both natural and man-made. Man-made sources appear to be most amenable to successful control. Some natural sources, particularly discrete sources, may also be controlled. Control measures may be employed to either remove the salt load from the river system at the point of discharge from the source or to reduce water flow through an area of salt pickup and thus reduce the salt contribution of such an area. Specific control measures which may be applicable in the Basin are discussed in the following sections.

Control of Natural Sources

A number of natural sources of salt existed in the Basin prior to man's arrival. These sources remain relatively unchanged in magnitude by man's activities. The necessary technical knowledge is available to control some natural salt loads. However, the economic feasibility of such control has not been fully evaluated.

Natural Discrete Sources. Discrete sources encompass flow from springs, seeps, and other localized, concentrated discharges. Since such sources contribute high salt loadings from a small area, effective control may be technically feasible. Discrete sources may be controlled by removing the entire discharge from the river system, by removing only the salt load from the system, or by preventing any discharge from the source.

A number of discrete sources discharge to small tributary streams or have well defined discharge channels. In such cases the entire discharge may be intercepted and appropriate control measures applied. The intercepted flow could be conveyed to an impoundment and confined for evaporation, thus effectively removing the entire discharge from the river system. Application of this measure requires adequate area for an evaporation closed basin. Such impoundments may be developed and managed for recreation, wildlife habitat, or other beneficial uses. One drawback to this measure is that evaporation losses in the basin are increased. This should be utilized for moderate to highly mineralized discharges or no net reduction in salinity will occur.

Small sources of highly concentrated brines may be controlled by subsurface disposal. This method is feasible only if suitable geological formations are available to confine the brine and prevent any return flow to the river system.

Demineralization of the collected discharge is an effective means of removing the salt load from the river system with only

a small depletion of water discharged by the source. Two factors limit the feasibility of demineralization. The concentrated brines resulting from this process must be disposed of by one of the two methods discussed earlier. The most serious limitation is the lack of a low coast method of demineralization for the small discharges contributed by discrete sources.

In a few cases, mineral springs may be the outlet for an aquifer confined by impermeable boundaries on all sides. It may be technically feasible to plug the aquifer outlet or to apply hydrostatic pressure to suppress aquifer outflow. Such action could completely eliminate the discharge and salt load from such sources. However, a more probable result, following a period of adjustment, would be that the same volume of flow would reappear at some higher elevation near the aquifer recharge area. In this case the discharge would probably have a much lower salinity concentration. Thus, the salt load would be reduced with little or no loss of aquifer yield.

Natural Diffuse Sources. Over half of the salt load discharged to the Upper Basin river system is contributed by surface runoff and ground water inflow from diffuse sources. Surface runoff picks up salts as it passes over the surface of the soil and salt-bearing formations. Additional salt is believed to be picked up from sediments carried in suspension by streams. Ground water picks up salt as it percolates through the soil profile and moves through aquifers. Measures for controlling diffuse sources are thus aimed at reducing the opportunity for surface runoff and groundwater to leach or dissolve minerals from soil

and underlying geological formations.

Salinity contributions from natural runoff may be decreased by various measures aimed at reducing the extent and amount of water infiltration in areas of high salt pickup. For example, contour ditches might be constructed to intercept runoff and carry it rapidly into the stream, and surface sealants might be used to control the percolation of surface waters into the soil profile. In local areas where salt is picked up from formations crossed by the stream channel, it may be possible to construct an impervious channel or a bypass channel to prevent contact of water with the saline formation.

Highly mineralized groundwater is discharged by aquifers in some areas. By utilizing diversion or surface sealing techniques to reduce the recharge of the aquifer, displacement of this saline groundwater could be reduced with resulting reductions in salt loads discharged to the system. This approach may also have application to the control of mineral springs.

Percolation of water into the alluvium and shallow ground water underlying river valleys exposes water to the underlying formations much like the percolation of irrigation return flows. Reducing the underground movement of such water should, in most cases, reduce the salt load derived from valley soils and underlying formations.

Sediment swept into the stream from sheet and channel erosion is weathered by continued exposure to well aerated water, and by persistent turbulent mixing. The amount of salt

contributed from this source is not known. Numerous erosion control measures have been developed for land protection but little is known about how they affect salinity. Additional study of sediment and salinity relationships will be required to devise effective control techniques.

All of the control measures discussed above involve some form of modification of the movement of surface or groundwater. Flood control, wildlife habitat and water rights are just a few of the various factors that should be carefully evaluated before such modifications are carried out.

Control of Man-Made Sources

Man has increased the salt burden carried by the river system by the discharge of municipal and industrial wastes and by heavy utilization of water for irrigation. Since man has control of such water use, these sources of salt may be more completely controlled than natural sources.

Municipal and Industrial Sources. Municipal wastes are generally relatively low in salinity. With the exception of oil field brines and uranium mill effluents, industrial wastes are also relatively low in salinity. The most effective means of controlling these salt sources are lagooning and evaporation of the wastes, injection into deep formations, or discharge into closed basins. These control measures result in the removal of the entire waste flow from the river system. Due to the low salinity concentrations, the loss of water involved in eliminating such waste discharges would, in most cases, offset

decreases in basin salinity levels resulting from removal of salt from these sources. Thus, salinity control measures should be considered for only the most concentrated sources.

Several abandoned oil test wells discharge highly mineralized water. Such flowing wells can frequently be controlled by plugging the casing with concrete. Alternatively, the discharge can be disposed of in the same manner as natural spring flow.

It should be noted that since the salt load from municipal and industrial sources represents a small fraction of the total basin salt burden, complete control of such waste discharges would have little effect on basinwide salinity problems.

Irrigation Return Flows. Irrigation contributes an increased salt load to the river system in a number of different ways. When new land is brought under irrigation, any highly soluble salts present in the soil are leached out by the irrigation water in a relatively short period of time. As irrigation continues, additional salts are dissolved from the soil. These dissolved salts are picked up by any excess irrigation water and returned to the river system as surface wastewater or as groundwater flow. This pickup of salts from the soil by return flows may continue for many years.

The major portion of return flows usually percolates downward into the groundwater aquifer and then moves horizontally either into drains or to the river system. If the groundwater is highly saline, the return flows may displace large volume of the saline groundwater with resultant large salt loads entering the river system. Return flows may also pick up significant

salt loads from aquifer materials or underlying formations if sufficient soluble salts are present in these locations.

Wastewater from inefficient practices may flow onto or under adjacent non-irrigated land. Evaporation from such lands concentrates salts drawn to the surface by capillary flow into a surface crust which is easily removed by surface runoff. Irrigation may thus indirectly contribute to salt pickup from non-irrigated lands.

Salt loads contributed by irrigation may be controlled by the proper selection of land to be irrigated, by reducing return flows to a minimum, and by intercepting return flows for treatment or disposal. Specific control measures are discussed in the following sections.

Land Selection. Many soils within the Colorado River Basin contain high concentrations of soluble salt. Irrigation of these soils results in high salt pickup by return flows during the initial leaching period. Large salt loads are also contributed by the irrigation of shallow soils overlying highly saline shales. Classification of all lands in the Basin would allow identification of these problem soil areas. Cessation of irrigation of shallow soils overlying shale would lower the Basin salt burden. It may be possible to purchase the water rights or the land and water rights and discontinue irrigation of some of these shallow soils. Major problems associated with purchase of this type of land would be the disruption of the owner's farm operation and the transfer of water rights to other land or

other uses. Some state water laws prohibit separating the water rights from the land or transfer or sale except for higher classified uses. Additional investigations and research are needed to determine the salinity control benefits which may be derived from land selection.

Canal Lining. Seepage losses from unlined irrigation canals are frequently large. These seepage losses contribute to the volume of return flows which pick up salt from groundwater aquifers. Reducing seepage would reduce the salt load of return flows in such cases.

Seepage losses also occur from farm ditches and distribution systems. In some areas canals are kept full during the non-irrigation season to provide livestock water. Providing enclosed or pipe distribution systems would reduce farm seepage losses. A pipeline system for winter livestock water supply would eliminate the need for maintaining flow in the canals year around.

Except for some areas where high value crops are grown, relatively little canal lining or use of pipe distribution systems has been accomplished in the Upper Basin. Thus, a high potential exists for large reductions in return flows as achieved by these types of systems.

Improved Irrigation Efficiency. Low irrigation efficiencies result in excess return flows. Improvement of irrigation efficiencies, as discussed in a preceding section on water conservation, would reduce the volume of return flows and reduce salt loads in the same manner as reducing canal seepage losses.

Drainage. Open surface drains and underground tile drains have been installed in a number of irrigated areas. These drains were usually provided to lower existing high water tables or to prevent water logging by irrigation. To reduce costs, drains were usually constructed as deep and as far apart as soil conditions would allow. Such practices result in long flow paths for return flows.

By installing closely spaced, shallow tile drains, salt loads may possibly be reduced by shortening the flow paths of return flows. Also, shallow drains may reduce the deep displacement of saline groundwater. Surface drains to intercept surface runoff and irrigation tailwater could also reduce the pickup of salt from non-irrigated lands.

Interception of Return Flows. Irrigation return flows reach the river system by a variety of routes. Much of the flow may occur as increased groundwater discharge spread over a wide area. In such cases interception of return flows may be difficult. In some cases, however, return flows may be collected by drains or small tributaries and concentrated into a single stream that may be easily intercepted and conveyed to a treatment or disposal facility.

Once collected, irrigation return flows may be controlled in the same manner as mineral springs discharges. Evaporation, desalination, and subsurface injection into geologically closed formations are technically feasible control measures. The practicality of utilizing these control measures for return

flows is limited however, by the same factors as discussed in the section on mineral springs.

CHAPTER IV. STATUS OF SALINITY CONTROL ACTIVITIES

A number of research, demonstration and technical investigation activities related to salinity control have been completed or are underway in the Colorado River Basin. These activities have substantially added to the knowledge of the Basin's salinity problem and have developed improved salinity control technology. In addition, research and technical investigations in other geographical areas have provided technology applicable to the Basin. In spite of this additional information and knowledge, present salinity control technology is still limited and additional research and technical investigations will be required before an effective salinity control program can be implemented. Information developed by these activities is sufficient, however, to provide a basis for preliminary estimates of the potential for salinity control presented in the following chapter. The following sections outline the current status of salinity control activities in the Basin and discuss some of the recent developments and their application to formulation of a salinity control program.

TECHNICAL INVESTIGATIONS

Technical investigations of the salinity problem have been conducted by the Colorado River Basin Water Quality Control Project of FWQA (Project) since 1963. An intensive water quality

sampling survey was conducted in 1963 and 1964 in the Lower Basin. A similar survey was made in the Upper Basin in 1965 and 1966. These surveys were designed to define the location and magnitude of all significant salt sources. In the Lower Basin, available water quality data was limited in a number of areas and an accurate evaluation of salt sources was not possible. Thus, the 1963-1964 investigation was the first attempt to accurately quantify Lower Basin salt sources.

The Geological Survey made an analysis of existing water quality data for the Upper Basin which was published in 1965.[9][10] Their report contained the first summary of the location and magnitude of salt sources in the Upper Basin and a comprehensive compilation of available data, and provided valuable information concerning hydrological and geological conditions contributing to high salt loadings. The 1965-1966 Project investigation supplemented the Geological Survey analysis by conducting more intensive quality sampling in a number of areas to better define specific locations of salt sources and by furnishing an additional check on Geological Survey estimates of the magnitude of those salt sources for which only limited data was available.

Data developed by the various investigations discussed above and by other short term surveys of specific salt sources provided the basis for estimates of the potential salt load reductions discussed in a later chapter. A detailed evaluation of the water quality data collected by the Project is presented in Appendix A.

Preliminary feasibility studies of several potential salinity control projects and control methods were made by the Project during 1964-1965. These studies provided an indication of the potential physical features and estimated costs of a limited salinity program. Since an evaluation of the economic impact of changes in salinity concentrations was not yet available, the economic feasibility of such a program could not be determined. Recently, available information and changing water resource development plans have invalidated some of the results of the feasibility studies. However, data developed by these studies were useful for estimating the potential for control of several salt sources. Study results were available in open file reports located in the Project office in Denver.

Early in FY 1968, the FWQA and the Bureau of Reclamation initiated a cooperative salinity control reconnaissance study in the Upper Basin to identify controllable sources of salinity, determine technically feasible control measures and estimate their costs. The first year of this study was financed by a transfer of funds from FWQA to the Bureau, and the second year was financed by the Bureau. A shortage of funds forced discontinuance of the study at the beginning of FY 1970. A report entitled "Cooperative Salinity Control Reconnaissance Study, Upper Colorado River Basin," presenting the results of the study is scheduled for release during 1970.

Reconnaissance level preliminary plans were developed by the cooperative study for two salinity control projects and cost

estimates prepared for a number of control measures. A preliminary Project plan was developed which would eliminate the heavy pickup of salt by the Dolores River as it crosses a salt anticline in Paradox Valley in western Colorado. A detention dam to reduce peak flood flows and a concrete channel to flume the stream through the valley would be utilized to control this source. Details of the project are discussed in Chapter V. Average annual costs of the project were estimated to total about four dollars per ton of salt removed from the river system. By way of comparison, salinity control benefits are estimated to range from about five dollars per ton of salt removed in 1970 to twelve dollars per ton in the year 2010. This project would thus appear to be economically feasible.

A preliminary plan was also prepared for a project to control the salt load from Crystal Geyser, an abandoned oil test well which periodically discharges highly mineralized water in much the same manner as a geyser. Control would be achieved by collecting the geyser discharge and pumping it to a lined impoundment for evaporation. Average annual costs were estimated to total about five dollars per ton of salt removed. A project of this type would be potentially applicable to control of some of the more concentrated mineral springs if suitable land areas for evaporation ponds can be found and evaporation rates are high enough.

For control of irrigation return flows, the costs of impounding and evaporating the flows at two topographically different

sites were estimated. Annual costs of such controls would appear to be in the range of $7 - $15 per ton of salt removed. Deep well injection of relatively small quantities of the more concentrated return flows was estimated to cost about $10 - 15 per ton of salt removed. The feasibility of controlling irrigation return flows by evaporation or deep well injection would appear to be marginal on the basis of salinity control benefits alone.

The cost of lining canals and distribution systems in several existing irrigation projects as a salinity control measure was also investigated. Construction costs of such lining was estimated to range from $200 - $550 per acre, depending upon the complexity of the conveyance system. These costs are not readily convertible into a cost per ton of salt removed as the effectiveness of this control measure has not yet been fully evaluated. A canal lining demonstration project to provide the basis for such an evaluation is currently underway and is discussed in the following section.

Following a discontinuance of the cooperative study at the start of FY 1970, the Project initiated a preliminary study of a project to control the salt load from several large mineral spring areas in the vicinity of Glenwood Springs, Colorado. This study has been completed and an open file report is in preparation. Details and feasibility of this project are discussed in Chapter V.

A preliminary study of control measures for LaVerkin Springs, a large thermal spring discharging significant quantities of

radium-226 and mineral salts to the Virgin River in Southern Utah, was initiated by the Project in March 1970.

RESEARCH AND DEMONSTRATION ACTIVITIES

A number of research and demonstration projects are presently underway which are expected to contribute significantly to the development and/or evaluation of various salinity control measures. Three projects are directed toward the development of techniques for minimizing salinity contributions from irrigated agriculture including a demonstration of the salinity control potential of lining irrigation canals and distribution systems. Another research project just completed has demonstrated the application of the analog computer to the simulation of the salt flow system in the Upper Basin. A fifth project recently initiated will evaluate the movement of salts in a groundwater system. These five projects were financially supported by the FWPCA. Additional research sponsored by various universities in the western states is expected to contribute improved salinity management technology. Various research projects have been proposed which, if funded and carried to completion, would substantially increase the store of salinity control technology. The following paragraphs outline the status of current activities, discuss significant research results and their application, and outline the areas of greatest need for additional salinity control research.

A research project entitled "Quality of Irrigation Return

Flow" was initiated during FY 1969 by Utah State University at Logan, Utah, under a FWQA research grant. This project has the dual objectives of increasing the knowledge of basic processes controlling the movement of salts in solids and the application of this knowledge to the development of salinity control measures. Research to date has been conducted on a small scale in the laboratory and in greenhouse lysimeters. A digital simulation model is being developed to accurately predict the movement of salts and changes in the quality of applied irrigation water within the soil and root zone. This model will be utilized to design on-farm irrigation practices, such as rate and timing of irrigation applications, so as to manage the salinity concentration of soil moisture in the root zone within acceptable limits for the specific crop being grown while minimizing the salt load contributed by the farm. This model will be refined in the future to optimize the on-farm irrigation practices of an entire irrigated area in such a manner that high irrigation efficiencies would be obtained, a salt balance would be maintained in the root zone and the pickup of additional salts from the soil profile would be minimized.

Preliminary research results indicate that it may be feasible to seasonally store salts contained in the applied irrigation water in the lower soil zone during low streamflow periods and then leach these salts out during normal or high streamflow periods. Such salt storage would help reduce the wide seasonal variations in stream salinity concentrations presently occurring in much of the Upper Basin.

The University has established a 40-acre test farm in Ashley Valley near Vernal, Utah, to provide full scale field testing of laboratory results. Field tests will be conducted during 1970 and 1971. Establishment of the test farm in this location will demonstrate salinity control measures under conditions similar to those found in many Upper Basin irrigated areas.

In response to a request from the FWPCA, a large scale research project entitled "Prediction of Mineral Quality of Return Flow Water from Irrigated Land" was initiated by the Bureau of Reclamation in the latter part of FY 1969 with financial support provided by a transfer of funds from the FWPCA.[11] The primary objective of this project is to develop a digital simulation model which will accurately predict the quantity and quality of irrigation return flows from an entire irrigation project with known soil groundwater, geologic and hydrologic characteristics. Such a model would have several applications. The water quality impact of a proposed irrigation development could be more accurately assessed than by any presently available techniques. More importantly, the model could be utilized to evaluate the water quality effects of alternative project designs thus allowing selection of the optimal design of proposed project features in order to minimize any adverse effects on mineral quality. Another application would be the evaluation of improvements of irrigation facilities and practices in established irrigated areas aimed at reducing present high salt contributions.

Field studies will be conducted in a number of locations with various soil and geologic conditions to verify prediction techniques under a wide range of conditions. Ashley Valley, surrounding Vernal, Utah, was selected as the initial study area. Characterization studies of this area are currently underway. Initial runs of an elementary simulation model will be made during 1970 using present data. The model will be refined and additional data collected during the next three years. Field studies at other locations will be initiated at some future date.

The Utah State University and Bureau research projects are being closely coordinated. Although aimed at different objectives, these projects are complementary and data collected by each project, theoretical results and other information are being exchanged. Establishment of the Vernal test farm by the University will aid in this coordination. The simulation models being developed by the two projects differ substantially in purpose and scope. The University model is limited to on-farm irrigation practices and movement of salts within the soil zone only. It can thus optimize irrigation practices to minimize salt pickup from the soil zone of the farm only. Salt pickup from the groundwater system and the effects of off-farm water losses, such as canal seepage, on the total salt load contributed by an irrigated area are not evaluated. This model is primarily a design and farm management tool. In contrast, the Bureau of Reclamation model will simulate all water and salt

movement occurring in an entire irrigation project including the groundwater system. This will provide an evaluation of the salt pickup in the groundwater system and at other off-farm locations as well as the on-farm pickup. The salinity effects of alternative designs for conveyance systems, surface and subsurface drains, etc., can thus be evaluated.

The Grand Valley Salinity Control Demonstration Project at Grand Junction, Colorado, was initiated in FY 1969 under a FWPCA demonstration grant. The objective of this project is to demonstrate the salinity control potential of lining irrigation canals and laterals. The Grand Valley is underlain by an aquifer containing highly saline groundwater. Seepage from canals and laterals contributes to the recharge of this aquifer. This recharge displaces the saline groundwater into the Colorado River, increasing its salt load. Reduction of such recharge by reducing seepage from conveyance systems is thus expected to reduce the salt load discharged to the river.

A major portion of the canals and some of the laterals serving a study area of about 4,600 acres were lined with concrete during the 1969-1970 winter season. Additional canal and lateral lining will be done during the 1970-1971 winter season. Most of the lining is being accomplished by a corporation of local irrigation and drainage districts which directs the demonstration project. Colorado State University is conducting the data collection activities and evaluation of salinity control effects under contract from the corporation. A simulation model is

being developed which will evaluate the effects of changes in irrigation efficiency on salt load contributions as well as changes in seepage losses from the conveyance system. This model will allow the results of the demonstration project to be projected valley-wide upon completion of the study to form the basis for future salinity control activities in this location. Completion of the demonstration project, including all post-construction studies, is scheduled for mid-1972.

Only limited research efforts are presently directed toward defining processes controlling salt loading from natural sources. The FWPCA is providing financial support for one such effort entitled, "Electric Analog Simulation of the Salinity Flow System within the Upper Colorado River Basin", which is nearing completion at Utah State University. The results of this research will provide new information concerning the distribution of salt sources in the Upper Basin and will provide an analytical tool for evaluating the water quality effects of various salinity control measures. The final research report is scheduled for publication during 1970.

A research project entitled "Effect of Water Management on Quality of Groundwater and Surface Recharge in Las Vegas Valley", was initiated by Desert Research Institute in late 1969 under a FWPCA research grant. This project will evaluate, among other things, the movement of salts in the groundwater system and the exchange of salts between the groundwater and surface waters of Las Vegas Wash. Research results will help define the optimum approach to control of this salt source. Completion

of the research effort is scheduled for mid-1973.

A cooperative regional research effort, "Project W-107, Management of Salt Load in Irrigation Agriculture", was initiated in 1969 by seven western universities and the Agricultural Research Service's U. S. Salinity Laboratory. Work underway or planned covers a wide range of salinity management aspects and should provide a number of results of applicable to Basin salinity problems. The FWPCA is participating in the coordination of this research effort.

Completion of the various research and demonstration projects currently underway will provide much new information which will be useful in the formulation of a basinwide salinity control program. However, additional research and demonstration activities are needed to develop control measures for those salt sources for which no practical control measures exist and to insure that those control measures selected for implementation in a basinwide program will be the most effective and economical. A practical means of controlling small mineral springs needs to be developed and demonstrated. Application of desalination techniques to control of salt sources in mountainous areas is severely limited by the lack of a suitable method of brine disposal. Thus, a need exists for development of brine disposal methos which can be applied in areas with high precipitation and low evaporation rates. Additional methods of controlling diffuse natural sources, the major contributor of salt loads, are needed. Significant reductions in salt loads can be achieved by improving irrigation facilities and practices only if the economic

advantages of implementing such improvements can be demonstrated to the individual irrigator. A number of demonstration projects of this type are needed. Additional control measures applicable to irrigated agriculture need to be developed and demonstrated. Thus, the scope and magnitude of research and demonstration needs is large.

A number of research proposals related to salinity control have been submitted by various universities in the Colorado River Basin region. Subjects of these proposals include demonstrating the relationships that exist between irrigation practices, crop yields and the salinity of return flows· evaluation of the salinity effects of drainage system operations in the Yuma area, and determination of the relative magnitude of natural and man-made salt contributions in an irrigated area. The range of research objectives shown by projects proposed or underway demonstrate the wide range of research expertise available in the area of salinity control. Thus, the expertise required to carry out needed research efforts is available at institutions in the Colorado River Basin region.

SALINITY CONTROL PROJECTS

During the latter part of FY 1968, the FWOA made funds available and requested the Bureau of Reclamation to select a pilot project to test and demonstrate control methods for reducing salinity concentrations and salt loads in the Colorado River system. The plugging of two flowing wells, the Meeker

and Piceance Creek wells near Meeker, Colorado, was selected as the pilot demonstration project. The Bureau of Reclamation contractor completed plugging the Meeker well on August 3, 1968, and the Piceance Creek well on August 9, 1968. Closing of the Meeker well reduced the sodium and chloride concentrations of the White River by over 50 and 75 percent, respectively, at the Geological Survey gage below Meeker. Plugging the Piceance Creek well decreased the sodium, bicarbonate, and chloride concentrations over 10 percent at the mouth of Piceance Creek, 13 miles downstream from the well. The salinity load of the White River and the Colorado River system was reduced by about 62,500 tons annually. This is about 19 percent of the average annual salinity load in the White River near Watson, Utah. Plugging the Meeker and Piceance Creek wells initially decreased the annual flow of the White River by about 2,380 acre-feet. It is the opinion of the Bureau's regional geologist that the flow formerly discharged from the wells will reappear through natural springs nearer the discharge area at an improved quality, and that plugging the wells will not cause a decrease of the annual flow in the White River.

Costs for plugging the two wells totaled $40,000. It is estimated that the present worth of total benefits which will accrue to Colorado River water users is approximately $7 million. This project demonstrated the economic feasibility of plugging similar flowing saline wells in addition to demonstrating significant local water quality improvement. The high

benefit-cost ratio for this project would indicate that plugging wells discharging considerably lesser amounts of salt would be economically feasible.

Another flowing well near Rock Springs, Wyoming, which contributed approximately 5,000 tons of salt annually, was plugged in November 1968, under the direction of the Wyoming State Engineer. The effects of eliminating this salt source have not been evaluated.

In late 1969, the Utah Oil and Gas Commission plugged seven abandoned oil test wells near Moab, Utah. This action eliminated a salt load of approximately 33,000 tons per year which was formerly contributed by two of the wells. The other five wells were not flowing. Costs of plugging the wells totaled about $35,000.

It is estimated that plugging the five flowing wells in Colorado, Wyoming and Utah will reduce the average annual salt load passing Hoover Dam by 100,000 tons or 0.93 percent. This salt load reduction would reduce average salinity concentrations by about 6 mg/l under present conditions. Although this change in salinity concentrations is small with respect to present salinity levels, the resulting economic benefits are significant. These benefits are estimated to range from $0.4 million annually in 1970 to $1.0 million annually in the year 2010 and have a present worth of more than $10 million. Thus, a modest but significant start has been made toward reducing the economic impact of rising salinity concentrations.

CHAPTER V. ALTERNATIVES FOR MANAGEMENT AND CONTROL OF SALINITY

Three basic approaches, or a combination of these approaches might be used to achieve a solution to the salinity problem: do nothing, limit development or implement salinity controls. The first approach would achieve no management of salinity control works. This approach, in effect, ignores the problem and allows unrestrained economic development at the expense of an increased adverse economic impact resulting from rising salinity concentrations.

The second approach would limit economic or water resource development that is expected to produce an increase in salt loads or streamflow depletions. Such an approach would minimize future increases in the economic impact of salinity and possibly eliminate the need for salinity control facilities. This approach has the obvious disadvantage of possibly stagnating growth of the regional economy.

The third approach, calling for the construction of salinity control works, would allow water resource development to proceed. Salinity controls would be implemented to meet a number of alternative management objectives. At least three possible management objectives could be considered: (1) salinity controls could be implemented to maintain specific salinity levels; (2) salinity could be maintained at a level which would minimize its total economic impact; and (3) salinity could be maintained at some low level for which the total economic impact of salinity

would be equal to the impact that would be produced if no action were taken at all. These objectives will be discussed in more detail in later sections. This approach would require substantial expenditures for control works.

The following sections discuss an evaluation of the costs and benefits of various levels of salinity control and a comparison of the relative economics of the three basic salinity management approaches discussed above.

POTENTIAL ALTERNATIVE BASINWIDE SALINITY MANAGEMENT PROGRAMS

There are a number of technically feasible salinity control measures which could be potentially useful for management of salinity in the Colorado River Basin. Various factors, including economic feasibility, and legal and institutional constraints, limit the present practicality of many measures, and reduce the potential means of managing salinity to a few basic approaches.

The most practical means of achieving reductions in salt loads include impoundment and evaporation of point source discharges, diversion of streams around areas of salt pick-up, improvement of irrigation practices and facilities to reduce return flow volumes, desalination of saline discharges from natural and man-made sources, and desalination of water supplies at the point of use. Augmentation of streamflow can be achieved by importation of water from other basins, by importation of demineralized sea water, and by increasing precipitation and runoff in the basin utilizing weather modification techniques. The control measures could be implemented in a variety of

locations and combinations to achieve basin wide management of salinity. An optimal management program would probably include each of these methods in some combination as well as other salinity control measures such as water conservation.

The following sections discuss the physical features, estimated costs, and water quality effects of eight potential alternative programs incorporating these two major management approaches. These programs included three salt load reduction programs, four flow augmentation programs, and one program to treat water supplies at the point of use. A comparison of these alternative programs indicates that a large-scale salt load reduction program would be the most economical means of achieving basinwide management of salinity. This salt load reduction program was thus selected to establish the potential scope and costs of a basinwide program designed to meet various alternative salinity management objectives discussed in a later section.

Salt Load Reduction Programs

Reduction of salt loads at their source appears to be the most practical approach to management of salinity. By preventing highly mineralized waters from reaching the stream system or by reducing the pickup of salts by high quality water, substantial reductions in salinity concentrations may be achieved at costs relatively low in comparison with most other measures. A variety of control measures would be employed by a low cost salt load reduction program. The major features of two such programs are outlined in the following paragraphs. A salt load reduction

program employing desalination techniques only (resulting in higher program costs) is discussed in a later section on desalination.

Full Scale Salt Load Reduction Program--One potential basin-wide salt load reduction program was formulated which would seek to control a major fraction of the salt load contributed by five large natural sources and 12 irrigated areas. The major features of this program are listed in Table 2 with potential control project locations shown in Figure 3. The selection of salt sources to be controlled, physical features of each project, and estimates of potential costs and salt load reductions were based on the latest information available from various research, demonstration and technical investigation activities. Present salinity control knowledge is still limited, however, and a number of assumptions were required to formulate the details of the program. The cost and effectiveness of estimates assigned to each project should, therefore, be considered representative of the approximate magnitude of expected costs and salt load reductions rather than detailed estimates of actual results to be achieved. Additional research and feasibility investigations would be required to refine these estimate and verify assumptions.

For a given project, construction costs and the actual salt load reductions achieved may vary over a wide range. Bayesian statistical decision theory was utilized, as outlined in a later section on salinity management costs, to estimate the expected (mean) value of possible costs and salt load reductions for each

Table 2. Potential Full Scale Salt Load Reduction Program

Project Description			Expected Average Annual Values			
No.	Location	Features	Total Project Costs ($1000/Yr)	Salinity Control Costs ($1000/Yr)	Salt Load Reduction (1000/Yr)	Cost Index ($/T)
1.	Paradox Valley, Colo.	Stream Diversion	700	700	180	3.89
2.	Grand Valley, Colo.	Irrig. Improvements	3,140	1,570	312	5.04
3.	Lower Stem Gunnison River Colorado	Irrig. Improvements	3,600	1,800	334	5.40
4.	Price River, Utah	Irrig. Improvements	1,000	500	89	5.65
5.	Las Vegas Wash, Nev.	Export & Evaporation	600	600	100	6.00
6.	Uncompahgre River, Colorado	Irrig. Improvements	4,000	2,000	320	6.25
7.	Big Sandy Creek, Wyo.	Irrig. Improvements	490	245	39	6.28
8.	LaVerkin Springs, Utah	Impoundment & Evap.	600	600	80	7.50
9.	Roaring Fork River, Colorado	Irrig. Improvements	880	440	52	8.47
10.	Upper Stem Colorado River, Colorado	Irrig. Improvements	1,420	710	80	8.88
11.	Henry's Fork River, Utah	Irrig. Improvements	710	355	40	8.88
12.	Dirty Devil River, Utah	Irrig. Improvements	710	355	40	8.88
13.	Duchesne River, Utah	Irrig. Improvements	5,660	2,830	273	10.37
14.	San Rafael River, Utah	Irrig. Improvements	1,360	680	65	10.48
15.	Ashley Creek, Utah	Irrig. Improvements	830	415	36	11.55
16.	Glenwood Springs, Colorado	Desalination	5,000	5,000	370	13.50
17.	Blue Springs, Ariz.	Export & Desalination	16,000	16,000	500	32.00
		Program Totals	46,700	34,800	2,910	

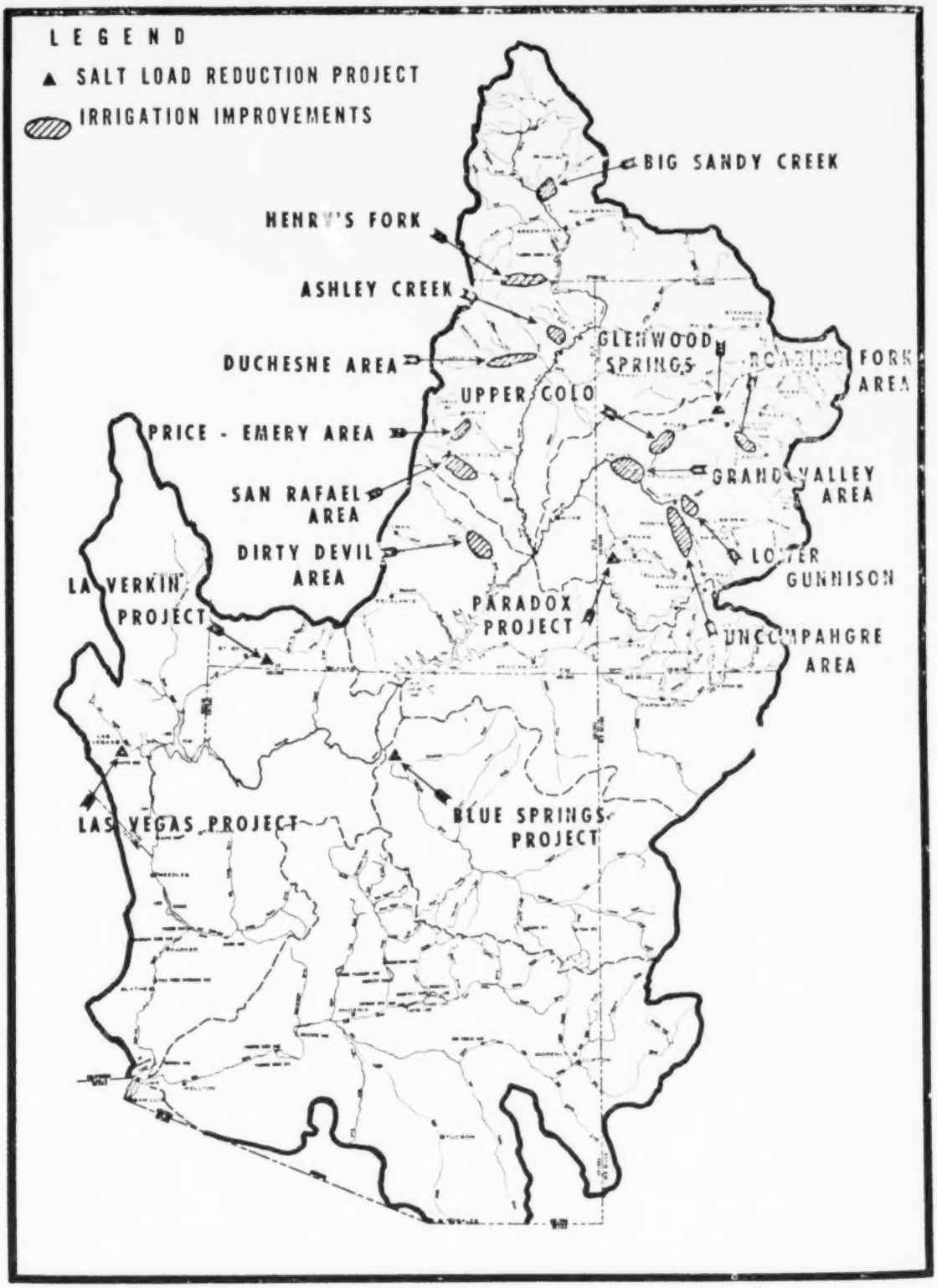

Figure 3. Location of Potential Salt Load Reduction Projects

project. The costs and salt load reductions shown in Table 2 are thus the expected values of a range of possible values for each project. The total estimated project costs shown are in terms of average annual costs which include amortized construction costs, operation costs and maintenance costs. A five percent discount rate was used for all cost estimated discussed in this chapter.

The Paradox Valley, Las Vegas Wash, LaVerkin Springs and Glenwood Springs salt load reduction projects would be single purpose only. For these facilities, all project costs were considered to be salinity control costs as shown in Table 2. The Blue Springs project would be a multiple purpose facility. However since only the costs of the salinity control portions of the project were estimated, the total project costs shown in Table 2 are all salinity control costs. Improvment of irrigation practices and facilities in the 12 irrigated areas selected would produce a number of benefits in addition to salinity control benefits. These benefits are estimated to be of about the same economic magnitude as salinity control benefits. For this reason, only half of total improvement costs were designated as salinity control costs.

Five salt load reduction projects utilizing various salinity control measures were selected for control of large natural discrete and diffuse sources. The sources selected represent those for which control appears to be most practical and economical at this time. It is possible that additional techni-

cal investigations and feasibility studies could result in the formulation of other more economical control projects for other sources. Details of the five projects selected are discussed in the following paragraphs.

The Dolores River picks up a large salt load as it crosses Paradox Valley in western Colorado. This salt pickup is believed to be the result of the recharge during periods of high streamflow of a groundwater aquifer in contact with the highly saline Paradox formation. Elimination of the salt load produced by such recharge conditions may be achieved by construction of a detention dam on the Dolores River upstream from Paradox Valley for reducing peak flood flows and by construction of a concrete-lined channel four miles long to convey streamflow through Paradox Valley. A preliminary plan for this project was developed by the Bureau of Reclamation as part of the Cooperative Salinity Control Reconnaissance Study.(12)

Interception of the outflow from Las Vegas Wash in Nevada and export to a dry lakebed in a closed basin was selected as the control project for this tributary. Export of the volume of flow currently leaving Las Vegas Valley would probably not be practical. However, future conditions may be significantly different. A comprehensive water pollution control plan is being developed for the Las Vegas metropolitan area.(13) Current waste disposal proposal call for tertiary treatment of all municipal and industrial wastes with the high quality effluent piped to the Colorado River below Hoover Dam.(14) Desalination

of the treated effluent might also be provided to allow a high degree of water reuse in the valley. Implementation of either a waste export or water reuse scheme would probably reduce the volume of flow in the Wash to an amount that could be economically exported. The project listed in Table 2 is based on the assumption that one of these schemes will be implemented. A research project was recently initiated by Desert Research Institute under an FWQA grant to define groundwater conditions in lower Las Vegas Valley. The final plan selected for regional waste disposal facilities and the results of the groundwater research will probably determine the final design of a control project for this salt source.

LaVerkin Springs are located in the Virgin River Basin in southern Utah. In addition to being a large salt source, these springs also discharges significant quantities of radioactive radium salts. Control of a major portion of the springs discharge could potentially be achieved by gravity conveyance to a large, lined pond for evaporation and storage. Concentration of the radium salts through evaporation could pose a potential radioactivity hazard. Commercial recovery of the radium may be potentially feasible, eliminating this hazard. Control of this salt source would produce significant local benefits as a result of reduced salinity in the irrigation supply for the Bureau of Reclamation's proposed Dixie Project and other local irrigation areas.

A number of large mineral springs and seeps, including Dotsero Springs, Yampa Springs, and Glenwood Springs, are

located along a 20-mile-long reach of the Colorado River near Glenwood Springs, Colorado. A reconnaissance study of this large salt source recently completed by the Project, showed that a large fraction of the combined spring flow could potentially be intercepted and conveyed to a central location.[15] A 16-mgd desalination plant could then be utilized to demineralize the collected flow with pure water returned to the river system. The concentrated brine could be disposed of by deep-well injection into a salt formation. No local market for the demineralized water now exists. However, should development of the oil shale deposits in the area materialize, the demineralized water could possibly be sold for municipal or industrial use to provide a source of income to offset part of the project costs. Sale of the concentrated brine for industrial use is another potential source of income.

Control of the major salt load contributed by the Little Colorado River, including the discharge of Blue Springs, would require the construction of a complex facility. The control works envisioned would be multiple-purpose and would include such major project features as a multi-stage, underground pumped storage hydroelectric plant located near the mouth of the Little Colorado River, a 250 cfs pumping plant located near the upper reservoir of the hydroelectric plant located near Flagstaff, a large-scale nuclear power plant including a 200-mgd desalination facility, and brine disposal facilities. Such a project would capitalize upon the expanding demands for electric

power in the Southwest and the water needs as a result of multiple use of facilities. A major portion of project pumping could be achieved during off-peak at low power costs. Sale of demineralized water to municipal and industrial water users in Central Arizona by discharge to the Verde River system would offset about half of the estimated desalination costs, thus reducing salinity control costs. The costs shown in Table 2 for this project include estimates for the aqueduct, pumping plant, desalination facility, and brine disposal facilities only. Costs were not estimated for the major hydroelectric and nuclear power facilities as these would not be directly related to salinity control.

Several factors control the feasibility of constructing a project of this magnitude. Perhaps the most serious potential limitation would be the relationship of this project and the Central Arizona Project with regard to Arizona's allotment of Colorado River water. If Colorado River flow is not augmented, delivery of 150,000 acre-feet annually from the Little Colorado River would require reducing the delivery of the Central Arizona Project by a like amount. Thus, that project's financing would be affected.

A second major factor is the need to sell the entire project concept to a major power company or consortium. The need for both base and peaking power production in this area has been shown by proposals for large-scale peaking power production at the Bridge Canyon Dam and proposals for large-scale fossil fuel

power facilities near Four Corners and other nearby locations. A potential demand for large power projects thus appears to exist.

A major portion of the salt load reduction effected by a full-scale basinwide program would be achieved by control of salt loads contributed by irrigated agriculture. Twelve large irrigated areas contributing the highest salt loads in the basin (three to six tons per acre per year) were selected for implementation of control measures. The total irrigated area of about 600,000 acres included in these 12 areas is only about 20 percent of the irrigated acreage in the basin but contributes more than 70 percent of the salt load attributed to irrigation sources.

Most of the irrigated areas selected have similar soil and geological conditions. The soils contain relatively high amounts of soluble salts and are generally underlain by moderately saline, shallow groundwater systems and highly saline shales or lacustrine formations. Under such conditions, excessive applications of irrigation water, poor irrigation efficiencies, conveyance system losses and other water losses result in large volumes of return flows which pick up salts from the soils and underlying formations. Control measures would be directed toward reducing such return flows. Due to slight variations in soil and geological conditions, the present condition of irrigation facilities, present levels of irrigation efficiency, and other variation between areas, the magnitude and scope of control measures would differ from area to area.

Estimates of the costs and salinity control effectiveness of the irrigation improvements selected for control measures were based on preliminary results of various research efforts currently underway. Installation of varying amounts of canal lining and distribution system improvements, closer control on water deliveries, modification of irrigation practices to substantially improve irrigation efficiencies, installation practices to substantially improve irrigation efficiencies, installation of some sub-surface drains, and other irrigation improvements would be required to achieve estimated levels of salt load reduction. These improvements would also produce a number of direct benefits to water users and irrigation districts in the form of water conservation, reduced maintenance costs, increased crop yields, and reduced fertilizer costs. These benefits are estimated to be of about the same magnitude as salinity control benefits. For this reason, only 50 percent of the total costs of irrigation improvements were designated as salinity control costs as shown in Table 2. Improvement of irrigation facilities and practices as proposed would require a great deal of local cooperation and a substantial local investment. Local educational programs would need to be expanded to teach irrigators how to improve their practices. More importantly, demonstrations of the economic feasibility of such improvements would be required to induce the irrigators to make the necessary local investment in facility improvements.

When completely implemented, it is estimated that the full-scale program outlined in the previous paragraphs and tabulated in Table 2 would achieve a total potential salt load reduction of 2.9 million tons annually at Hoover Dam. This represents a 27 percent reduction in the average annual salt load passing Hoover Dam for the 1942-1961 period of record adjusted to 1960 conditions of water use. Implementation of the full program in the period from 1975 to 1980 would result in reductions in predicted average salinity concentrations at Hoover Dam from 876 mg/l to 623 mg/l in 1980, and from 990 mg/l to 715/l in 2010. Average annual program costs, including amortized construction costs, operation costs and maintenance costs, are estimated to total $34.8 million. The 1970 present worth of total salinity control costs for this program for the period from 1975 to 2010 is estimated to be $375 million assuming a five percent discount rate.

Incremental Salt Load Reduction Program--Since the full scale program previously discussed is made up of a number of independent control projects, a number of alternative programs could be formulated by varying the time scale for implementing the individual projects. One such alternative program is discussed in the following paragraphs.

Implementation of the full-scale program by 1980 would reduce salinity concentrations at Hoover Dam below average concentrations for 1960 conditions of water use (697 mg/l) until beyond the year 2000. Achieving this degree of water quality enhancement

would require a heavy expenditure of construction funds over a short time period. An alternative plan to lengthen the implementation period could be formulated which would also achieve significant water quality enhancement. By phased or incremental implementation of the full scale program, a constant salinity level of 700 mg/l to approximate 1960 conditions could be maintained. A salt load reduction of 2.1 million tons per year in 1980 and 3.2 million tons per year in 2010 would be required to maintain this salinity level. Implementation of the first 13 projects listed in Table 2 would be required by 1980 to achieve this salt load reduction in 1980. Gradual implementation of the remaining four projects in the period 1980-2000 would be required to maintain the constant salinity level. A salt load reduction of 0.3 million tons per year would be required in 2010 in addition to implementation of the full scale program in order to maintain the 700 mg/l salinity level. In order to estimate program costs, it was assumed that additional control projects could be formulated in the future to achieve the added reduction for unit costs comparable to average program unit costs.

Average annual salinity control costs of the 13 projects to be implemented by 1980 were estimated to total $12.7 million. Average annual costs would increase with time as additional control measures are implemented reaching an estimated $39.4 million in 2010. The 1970 present worth of total salinity control costs for this phased implementation of a salt load

reduction program over the period from 1975 to 2010 is estimated to be $230 million. Total costs of a program implemented in increments as discussed are thus substantially less than for immediate implementation of a full scale program.

Flow Augmentation Programs

A second means of effectively reducing salinity concentrations would be to dilute existing streamflow with high quality water. For the Colorado River Basin, such flow augmentation could potentially be obtained from three sources - weather modifications, interbasin transfer, and desalination of sea water. A number of schemes have been proposed which would utilize these sources to provide varying amounts of flow augmentation. The costs and salinity control potential of three such schemes are discussed in the following sections. A fourth scheme utilizing demineralized sea water as a flow augmentation source is discussed in a later section entitled desalination programs.

Weather Modification Program--Increasing the runoff in the Basin by stimulating precipitation through utilization of weather modification techniques is one potential means of augmenting streamflow. The Bureau of Reclamation has estimated that as much as 1.87 million acre-feet of additional streamflow could be made available in the Upper Basin by a full-scale weather modification program at an annual cost of $2.65 million.(6) The salinity control effects of such a program will vary depending upon the locations at which the supplemental supply would be utilized. If the additional supply was consumptively

used in the Upper Basin, the salt load in the Lower Basin would be increased without accompanying dilution and the salinity problem would be compounded. If the entire supplemental supply was consumptively used in the Lower Basin however, it would result in substantial reductions in salinity concentrations.

The United States is required by the Mexican Treaty to deliver 1.5 million acre-feet of Colorado River water to Mexico annually. Meeting this treaty requirement has been declared a national obligation. The estimated volume of flow potentially available from a weather modification program is about equal to the amount that would be required to offset a proportionate amount of reservoir evaporation and river system losses and deliver 1.5 million acre-feet to Mexico annually. Thus, a potential use for the increased supply would be to provide the required Mexican deliveries. Utilization of the water in this manner would significantly reduce salinity concentrations throughout the lower river system.

Weather modification activities would be aimed primarily at augmenting snow accumulations in high mountains areas. The resulting increases in runoff would be primarily in the form of high quality Spring snowmelt. This Spring runoff would normally reach Lake Mead with a salinity concentration of about 300 mg/l. This concentration was used to estimate the increase in salt burden that would accompany the additional streamflow.

Assuming that the additional streamflow passing Hoover Dam would average 1.7 million acre-feet annually, flow augmentation

from this source would reduce predicted average salinity concentrations at Hoover Dam from 876 mg/l to 783 mg/l in 1980 and from 990 mg/l to 870 mg/l in 2010. At an average annual cost of $2.65 million, the present worth of weather modification program costs from 1975 to 2010 was estimated to be $32 million.

Augmenting streamflow would produce substantial direct benefits in addition to salinity control benefits. These benefits, such as increased power production, increased water supply, etc., were not evaluated but are known to have a large economic value. If program costs were allocated in proportion to resulting benefits, as was done for irrigation improvements as discussed in a previous section, the costs assigned to salinity control would probably be less than half of total costs. Weather modification may therefore be the most economical means of achieving salinity control. The magnitude of control that can be achieved in this manner is limited, and the practicality of weather modification has not been demonstrated. If weather modification becomes practical, a combination of flow augmentation from this source and the more economical elements of the salt load reduction program could achieve a high degree of salinity control for moderate costs.

Limited Interbasin Transfer--It is possible that augmenting streamflow with larger volumes of water than the estimated volumes available from weather modification could eventually be achieved by interbasin transfer of high quality water. A number

of schemes have been proposed by public and private interests which would import varying volumes of high quality water from a variety of different sources.[19] The salinity control effects of these various schemes are dependent upon the quality of the import water, the point of importation into the Basin, and the locations of ultimate consumptive use as discussed in the previous section on weather modification. Since a significant salt load will also be imported into the Basin, the point of ultimate use becomes a very important factor in the degree of salinity control that can be achieved.

Several of the proposed transfer schemes would import water directly to Lake Mead. If an annual volume of 2.5 million acre-feet were imported to Lake Mead at a salinity concentration of 300 mg/l (representative of the quality of proposed sources when transmission loss effects are considered) and this increased supply was utilized in the Lower Basin, predicted average salinity concentrations at Hoover Dam would be reduced from 876 mg/l to 749 mg/l in 1980 and from 990 mg/l to 827 mg/l in 2010.

No detailed cost estimates are available from which the average annual costs of a limited interbasin transfer program could be determined. If a cost of $30 per acre-foot of water imported is assumed, average annual program costs would total $75 million. Assuming that the necessary facilities could be constructed between 1975 and 1980 (a very optimistic assumption), the present worth of program costs from 1975 to 2010 was estimated to be $800 million.

Augmenting streamflow by interbasin transfer would also produce substantial benefits in addition to salinity control benefits as discussed in the previous section on weather modification. Evaluation of these benefits is beyond the scope of the investigations undertaken by the Project. These benefits are known to have a large economic value and would probably reduce the fraction of program costs which would be allocated to salinity control to less than half.

Large-Scale Interbasin Transfer--Projections of future water demands in the Lower Basin indicate that an increase in water supply of more than 2.5 million acre-feet annually could be utilized. Several of the proposed transfer schemes would seek to meet this larger water demand. Large quantities of water would be available from these schemes for achieving substantial dilution and salinity control. Various levels of salinity control could thus be achieved by supplying larger volumes of flow augmentation.

For purposes of comparison with the salt load reduction program previously discussed, the volume of flow augmentation required to maintain a constant salinity level of 700 mg/l at Hoover Dam was determined. Assuming the imported water would have a salinity concentration of 300 mg/l, it is estimated that flow at Hoover Dam would need to be augmented by 3.9 and 5.9 million acre-feet annually in 1980 and 2010 respectively, to maintain a constant salinity level of 700 mg/l.

Again, assuming a cost of $30 per acre-foot, the average

annual costs of such an importation program are estimated to total $117 million and $177 million in 1980 and 2010, respectively. With an optimistic implementation period of 1975 to 1980, the present worth of total program costs from 1975 to 2010 was estimated to be $1,470 million.

This flow augmentation scheme would also produce substantial benefits which would reduce costs allocated to salinity control as discussed in the previous section.

Other alternative flow augmentation program of the type just discussed could be formulated to meet other water quality goals. The volume of flow augmentation required and total program costs would vary inversely with the target salinity concentration at Hoover Dam.

A third possible source of flow augmentation is demineralized sea water. Desalination plants located near the Gulf of California or the Pacific Ocean could provide a supply of high quality water for direct use in southern California or Mexico, or for augmentation of the Lower Colorado River. The Bureau of Reclamation has conducted a feasibility study of one such augmentation scheme. The results of the study are discussed in the following section on desalination.

Desalination Programs

Desalination installations could potentially be utilized to remove salt loads at their source, to reduce the salinity of a water supply at the point of water use, and to provide a source of high quality water for flow augmentation. Three alternative

programs which utilize desalination technology are discussed in the following sections.

Source Control Program--In contrast to the salt load reduction programs previously discussed which utilize a variety of control measures, a comparable source control program could be formulated which would utilize desalination plants only as the control measure. The plants would function to remove the salt load from such concentrated sources as mineral spring discharges, saline tributaries and irrigation return flows. Due to the scattered locations and relatively small magnitude of the various salt sources suitable for demineralization, a large number of small desalination plants would be required to achieve any substantial reduction in salt loads. The unit costs of operating such small plants are high.

Another factor affecting the economy of such a program is the lack of highly saline sources for demineralization. Some mineral springs in the Basin discharge water with salinity concentrations exceeding 20,000 mg/l, but the volumes of such highly saline flows are small. Much of the Basin's salt load is contributed by irrigation return flows and other discharges with concentrations below 4,000 mg/l. A detailed evaluation has not been made of the locations, magnitudes and salinity concentrations of sources suitable for desalination. Thus, an accurate determination cannot be made at this time of the volume and average concentration of the flow that would need to be demineralized to achieve a given salinity control objective.

However, utilizing several assumptions, it is possible to evaluate the approximate magnitude of a desalination program.

Supply Treatment Program--A major portion of the economic impact of future salinity increases could be eliminated by reducing salinity levels in the water supply diverted to southern California through the Colorado River Aqueduct and All American Canal. Desalination plants at Parker and Imperial Dams could be utilized to remove a portion of the diverted salt load and maintain desired salinity levels. These plants would be large scale and could operate more economically than the small scale plants utilized in the source control program. Also, brine disposal would be less of a problem at these desert locations. Due to the low concentration of the supply water (less than 1,500 mg/l) the volumes of flow demineralized would be large and total costs would be high.

To maintain a salinity concentration of 700 mg/l in the diverted flow would require the desalination of an estimated 1.4 and 1.6 million acre-feet annually in 1980 and 2010 respectively. At an estimated unit cost of $100 per acre-foot ($0.30 per 1,000 gallons), average annual program costs would total $140 million in 1980 and $160 million in 2010. Assuming a 1975 to 1980 implementation period, the present worth of program costs from 1975 to 2010 was estimated to total $1,570 million.

A supply treatment program would be single purpose and all costs would be allocated to salinity control.

Flow Augmentation Program--Demineralized sea water is another potential source for augmenting streamflow in the Lower Colorado River. The Bureau of Reclamation has conducted a reconnaissance study of one scheme to import demineralized sea water. (4) The source would be a large scale nuclear power and desalination facility located on the Pacific Ocean between Los Angeles and San Diego. A large aqueduct would convey the demineralized water overland to Hoover Dam. As investigated by the Bureau, this scheme would be constructed in stages and would provide 1 million acre-feet of flow augmentation in 1990, increasing to 2 million acre-feet in 2010. Average annual program costs were estimated to total $131 million.

If the full 2 million acre-feet of flow augmentation were made available in 1980, average salinity concentrations at Hoover Dam would be reduced to 710 mg/l and 740 mg/l in 1980 and 2010, respectively. On the basis of implementation between 1975 and 1980, the present worth of total program costs from 1975 to 2010 was estimated to be $1,400 million.

Such a flow augmentation scheme would increase the available water supply for salinity control and provide substantial multiple purpose benefits. Other flow augmentation schemes involving demineralization would also provide multiple purpose benefits; however, the extent to which these benefits would reduce the costs allocated to salinity control was not evaluated.

Comparison of Alternatives

The eight alternative salinity control programs discussed in the previous sections are not directly comparable. Variations in the magnitude and scope of the alternatives result in differences in the level of salinity control achieved. Also, some of the programs are single-purpose with all costs assignable to salinity control while other programs are multiple-purpose with substantial benefits from other than salinity control to offset part of the program costs. It is possible to make comparisons between similar alternatives and to select the alternative which appears to be the most economical for achieving basinwide management of salinity.

The estimated costs and salinity control effects of the eight alternative programs are summarized in Table 3. Salinity concentrations expected, if no controls are implemented, are also shown in the table for comparison purposes. Comparisons of similar alternatives and the basis for selection of the phased implementation of a salt load reduction program as the least cost alternative salinity control program are presented in the remainder of this section.

The first two alternatives programs listed in Table 3 are composed of identical salt load reduction measures and differ only in the timing of implementation. Alternative number one would implement the full program by 1980 while the second alternative would delay full implementation until about 2000. Salinity control and other benefits produced by early

Table 3. Comparison of Alternatives Salinity Control Programs

No.	Alternative Salinity Control Program	Average Salinity Concentrations at Hoover Dam		Average Amount Program Cost		Present Worth
		1980 (mg/l)	2010 (mg/l)	1980 ($ Million/Yr)	2010 ($ Million/Yr)	($ Million)
1.	Salt Load Reduction (Full scale implementation)	620	720	47	47	510
2.	Salt Load Reduction (Phased Implementation)	700	700	23	52	350
3.	Flow Augmentation (Weather Modification) (1.7 MAF/Yr)	780	870	3	3	30
4.	Flow Augmentation (Interbasin Transfer) (2.5 MAF/Yr)	750	830	75	75	800
5.	Flow Augmentation (Interbasin Transfer) (3.9-5.9 MAF/Yr)	700	700	118	177	1,470
6.	Desalination (Source Control)	700	700	41	62	510
7.	Desalination (Supply Treatment)	--	--	140	160	1,570
8.	Desalination (Flow Augmentation) (2.0 MAF/Yr)	710	740	131	131	1,400
9.	No Salinity Control	876	990	--	--	--

implementation do not justify the substantial difference in program costs. Therefore, alternative number two, phased implementation of a salt load reduction program, would be the most economical program.

Alternative number six, a source control program utilizing desalination techniques, is a single-purpose alternative which would produce salinity control effects identical to alternative number two. Since resulting program benefits would be less (no benefits in addition to salinity control) and program costs higher than alternative number two, the latter remains the least cost alternative.

The supply treatment program (alternative number seven) would not control salinity levels in all water supplies in the Lower Basin. This alternative would thus produce fewer benefits than alternative number six which is similar. Alternative number seven has a higher cost than number six and is therefore inferior economically.

The remaining four alternatives, numbers 3,4,5, and 8, all would increase the Basin in water supply to some degree and would produce substantital benefits in addition to salinity control benefits. These additional benefits have not been qualified, as such an evaluation was beyond the scope of Project investigations. These four alternatives are thus not directly comparable to the four previously discussed. A comparison can be made between the four flow augmentation programs, and the less economical programs eliminated.

A desalination program and a limited interbasin transfer program would provide about the same amounts of flow augmentation. Water supply benefits would be comparable for both programs. Salinity control achieved by importation of demineralized water would be greater than for importation of normal fresh water, however, the resulting difference in salinity control benefits would not justify the differences in program costs. Alternative number 4, the limited interbasin transfer program would thus appear to be superior to alternative number 8, the desalination program.

Alternative numbers 4 and 5 differ both in the amount of flow augmentation provided and in the degree of salinity control achieved. If it is assumed that water supply benefits are proportional to the amount of flow augmentation provided, the large scale program should produce about double the benefits of a limited program. The salinity control benefits of the large scale program would also be greater than for a limited program. Since the costs of a full scale program average less than half of those for a limited program, the large scale program, alternative number 5 should produce a greater net economic return and would be superior to alternative number 4.

A large scale flow augmentation program (alternative number 5) would produce the same level of salinity control, hence the same salinity control benefits, as the phased salt load reduction program (alternative number 2). These two alternatives are thus directly comparable with regard to salinity control.

However, program costs and the magnitude of additional benefits associated with the two programs are vastly different. Selection of the most economical alternative with respect to salinity control is therefore dependent upon the relative magnitude of other program benefits and resulting allocation of costs to salinity control. For the salt load reduction program, the present worth of salinity control costs was estimated to be $230 million. This amount is about 15 percent of the present worth of total program costs for large scale flow augmentation. Non-salinity control benefits would have to exceed 85 percent of total benefits before flow augmentation would become more economical. Because of the large difference in total program costs and a low probability that the necessary benefits ratio would be achieved, the salt load reduction program was selected as the least cost alternative.

The time required for implementation of control measures is another factor that supports the selection of the salt load reduction program. For purposed of comparison, an implementation period of 1975 to 1980 was assumed for all alternatives. With optimum progression of necessary studies, fund appropriations, etc., the initial phases of the salt load reduction program could be implemented by 1980. Such optimism is not realistic for large scale public works as envisioned for the flow augmentation program. A date of 1990, or 2000 would be more realistic for delivery of large volumes of water from another basin. Substantial increases in salinity levels and attendant economic impact would thus occur before control of salinity

by flow augmentation could be achieved.

A flow augmentation program utilizing weather modification techniques (alternative number 3) is not directly comparable to any other alternative. The salinity control that could be achieved by such a program is limited as are the salinity control benefits. For the level of control achieved, however, weather modification has the lowest unit costs. Substantial water supply benefits would also accrue to the program reducing costs allocated to salinity control. The practicablility of basinwide weather modification has not been demonstrated. For this reason and because of the limited degree of control that could be achieved, weather modification was not considered a practical alternative. Should the practicality of this approach be demonstrated in the future, a combination of a weather modification program and the more economical elements of a salt load reduction program would result in the minimum cost for achieving moderate levels of salinity control. Utilizing this combination to maintain a constant salinity level of 700 mg/l at Hoover Dam would result in a reduction of about one-third in total salinity control costs for the salt load reduction program alone.

In summary, on the basis of present knowledge of the technical feasibility, costs and practicality of various salinity control measures, the phased implementation of a salt load reduction program (alternative number two) appears to be the most economical and practical means of achieving basinwide

management of salinity. This alternative was therefore utilized as the basis for estimates of salinity management and total salinity costs discussed in a later section on economic aspects. The following section discusses several other factors that should receive consideration in the final formulation of an optimal basin-wide salinity management program.

Other Considerations

Diurnal, seasonal, and other short-term cyclical fluctuations in salinity concentrations occur throughout the basin. The fluctuations are the result of a number of natural and man-made factors including seasonal variations in streamflow, droughts, reservoir operations, irrigation system operations, etc. Present peak salinity concentrations occurring during such fluctuations in the Lower Colorado River are approaching critical levels for some types of salt-sensitive crops. Should these high concentrations be maintained for longer periods of time than at present as the result of severe drought or other factors, significant damage to such crops could occur. Some types of crops are most sensitive to high salinity levels during the germination period. The occurrence of short-term high peak concentrations during the period when seed beds are being irrigated could result in heavy damage to that crop even though average salinity concentrations during the irrigation season were lower.

The salinity control measures incorporated in the salt load reduction program previously selected as the best alternative for basinwide salinity control are designed primarily

to reduce long-term average salinity concentrations. By reducing the salt burden carried by the river system during low flow periods, partial control of peak concentrations would also be achieved. In view of the potential economic impact on water users, however, more positive means of controlling short-term fluctuations should be sought.

One potential means of minimizing short-term salinity fluctuations would appear to be the manipulation of reservoir storage and releases. Prior to the construction of Hoover Dam, salinity concentrations in the Lower Colorado River fluctuated widely from season to season and from year to year. The large volume of storage in Lake Mead has substantially dampened out these fluctuations. Lake Powell is expected to produce a similar dampening action. These large reservoirs do not produce a complete mixing of low and high quality inflow however, due to their long, narrow configurations. Consequently, Lake Mead has historically exhibited a tendency to pass higher salinity inflows, resulting from low runoff years, through the reservoir with relatively small reductions in peak concentrations. Reduced outflow from Lake Powell during periods of low inflow, in combination with large salt loads contributed by sources located between Lake Powell and Lake Mead, could result in short-term fluctuations in the salinity of Hoover Dam releases similar to those occurring prior to closure of Glen Canyon Dam. The potential for utilizing storage in Lake Powell and Lake Mead and coordinating releases from these reservoirs to minimize short-term salinity fluctuations should be investigated.

The fluctuating streamflow inherent in the operation of the various power plant, irrigation diversions, irrigation projects, etc., located along the Lower Colorado River in combination with the relatively uniform contribution of saline irrigation return flows are believed to be the source of significant short-term flucutations in salinity concentrations at Imperial Dam. Close coordination of all water operations, such as computer scheduling of on-farm irrigation deliveries and computer control of automatic flow controls, should be investigated as a potentially feasible means of eliminating such fluctuation.

Manipulation of reservoir storage and close coordination of water movements would appear to show substantial promise for minimizing fluctuations in the Lower Basin. In the Upper Basin, a lack of adequate storage for regulation of water movements on many tributaries would preclude control of fluctuations in this manner. One method which may be applicable in the Upper Basin is the seasonal storage of salt within the soil column in irrigated areas. The volume of salt reaching the river system during low flow periods could be reduced by this method thus reducing peak salinity concetrations. Salt balance would be maintained by leaching out the stored salt during periods of high runoff. This control method is currently under investigation at Utah State University as discussed in Chapter IV.

There are no water quality simulation models presently available which could be utilized to accurately predict the magnitude and timing of salinity fluctuations. Present methods of evaluating the economic impact of salinity on water users utilize long-term salinity concentrations and cannot evaluate the economic impact of short-term fluctuations. This analytical capability needs to be developed before the economic feasibility of controlling fluctuations can be assessed.

There are also a number of long-term salinity control measures which have not been evaluated for economic feasibility. Such measures as water conservation, cessation of irrigation of highly saline soils, etc., may have a definite place in an optimal salinity management program. Development of such a program should give careful consideration to all potential control measures.

One other area that should be investigated is the exchange of water at locations both in and out of the basin. For example, it might be possible to provide demineralized sea water to southern California in exchange for water presently diverted from the Colorado River. The water supply and water quality effects of such an exchange should be evaluated as a basis for comparison with other alternatives previously discussed.

ECONOMIC ASPECTS

There are various economic costs associated with the use

of a degraded water supply. Direct costs are incurred by water users. In addition, the regional economy suffers economic losses stemming from these direct costs. There are also costs associated with the control and management of salinity. Together, these costs constitute the total economic impact of salinity variations in terms of total costs corresponding to changes in salinity concentrations and thereby provide the basis for determining the economic feasibility of salinity control. The main components of salinity costs are discussed in the following sections.

Salinity Detriments

Salinity detriments are the costs associated with use of a water supply of a given salinity concentration and consist of two major components, direct detriments and indirect detriments. Direct detriments are the costs incurred directly by the water users and may take such forms as decreased crop yields, increased municipal and industrial water treatment costs, pipe corrosion, increased consumption of soaps and laundry additives, etc. Indirect detriments are the economic losses suffered by the regional economy which stem from the direct detriments. Different methods of analysis must be employed to determine these two component costs. Determination of the magnitude of direct and indirect detriments is discussed in the following sections.

Determination of Direct Detriments-- A detailed study of water use in the Lower Colorado River Basin and southern California water service area for present and future conditions

provided the basis for determination of direct detriments. The Southern California water service area includes Imperial and Coachella Valleys and those portions of the Los Angeles and San Diego metropolitan areas receiving Colorado River water. Estimated costs of using water of a given salinity concentration, predicted future average salinity concentrations and predicted future water ratio of use were utilized to estimate direct detriments. Detriment curves were prepared for 1960, 1980, 2010 conditions of water use and the salinity range expected during that time period. A detailed discussion of analytical techniques employed and a breakdown of the component costs are contained in Appendix B.

Determination of Penalty Costs--Differences in direct detriments associated with the use of water with different salinity concentrations are known as direct penalty costs. These penalty costs represent the marginal costs of using a degraded water supply.

The major emphasis of the economic studies conducted by the Project has been directed toward the determination of penalty costs as a means of assessing the economic impact of future increases in salinity concentrations. The results of Project economic studies in terms of penalty costs are presented in Appendix B. The analytical techniques employed to evaluate direct detriments (indirect penalty costs) utilize direct penalty costs as basic input. A determination of direct penalty costs is thus an interim step in the determination of total salinity detriments.

The relationship between direct detriments and direct penalty costs can be illustrated by the following example: Direct detriment curves for 1960, 1980, and 2010 conditions of water use are shown schematically in Figure 4. The direct detriments associated with use of water supplies with salinity concentrations of 700 mg/l and 900 mg/l in 1980 are shown by points "A" and "B" respectively. The difference between these detriments is a direct penalty cost for 1980 conditions associated with an increase in salinity levels from 700 to 900 mg/l.

To facilitate the determination of direct penalty costs, the water use and economic conditions existing in 1960 were selected as base conditions. For other time periods, increases in direct detriments resulting from increases in salinity concentrations above 1960 levels (697 mg/l at Hoover Dam) were calculated and designated as direct penalty costs. Direct penalty costs were determined separately for the Lower Colorado River subbasin and the southern California water service area.

Determination of Indirect Detriments--Input-Output analyses of the Lower Colorado River Basin and southern California economies were utilized as the basis for determination of indirect detriments or penalty costs. The analytical techniques utilized are discussed in Appendix B. Indirect detriments were determined separately for the Lower Colorado River subbasin, the Gila River subbasin and the southern California water service area. The combined totals of predicted direct and indirect penalty costs for the three areas for the

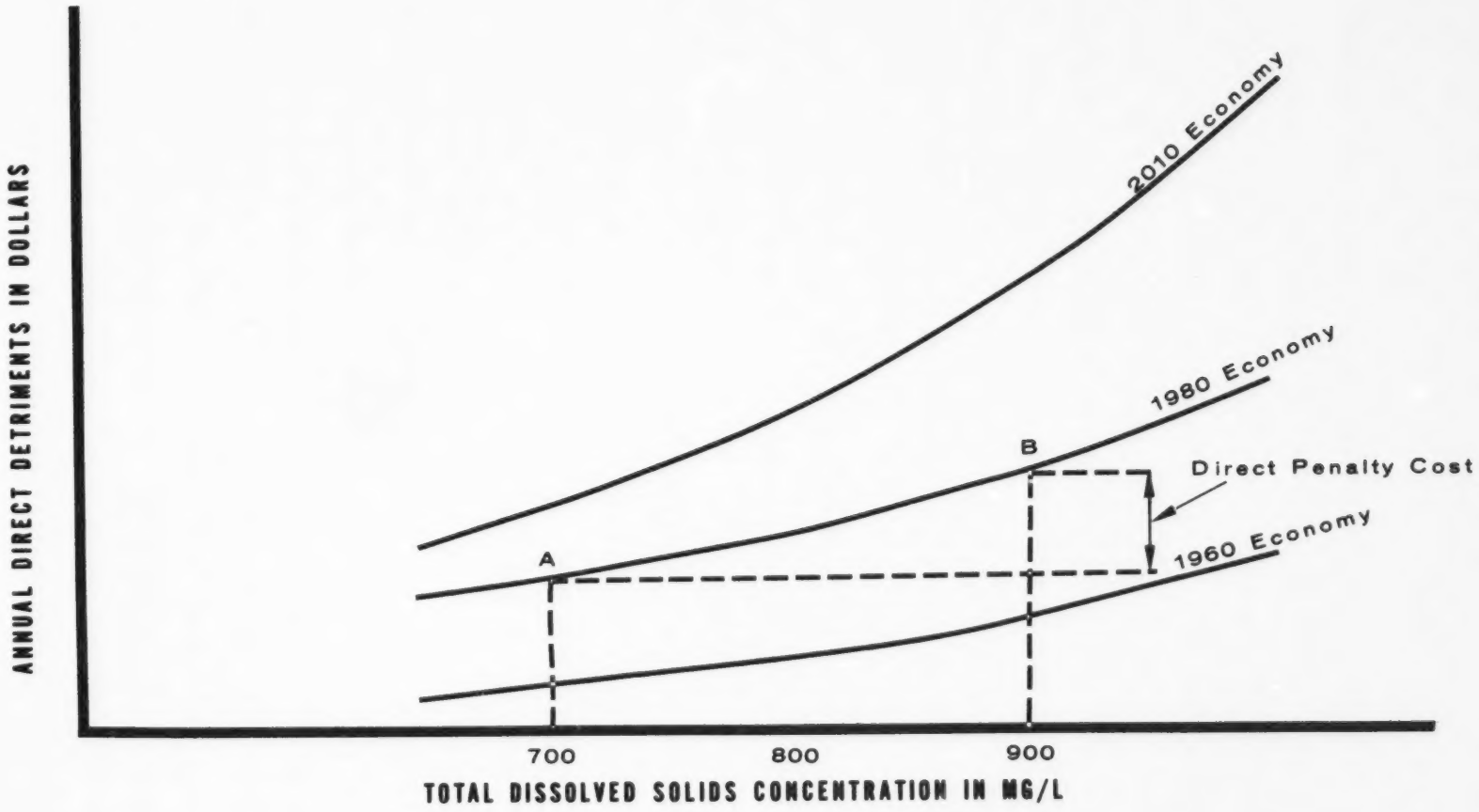

Figure 4. Illustration of Penalty Cost Evaluation

years 1980 and 2010 are summarized in Table 4. These costs are in terms of 1960 dollars.

A graphical summary of penalty costs is shown in Figure 5. It should be noted that penalty costs are related to salinity concentrations at Hoover Dam. Salinity concentrations at points of water use in the Lower Basin and Southern California can be directly related to salinity levels at Hoover Dam. Modifications of water volumes or salt loads in the drainage area of Lake Mead directly affect the salinity of Hoover Dam releases. Thus, the salinity concentration at Hoover Dam was selected as a convenient index of changes in Basin salinity levels.

Determination of Total Detriments.--To facilitate the evaluation of the economic feasibility of various salinity control measures, it was desirable to develop a series of detriment curves representing total costs to the economy of using a water supply with salinity concentrations at Hoover Dam varying from 600 to 1,000 mg/l and variations in the economy anticipated between 1970 and 2010 at 10-year intervals. Direct detriment curves developed for the evaluation of penalty costs discussed in the previous section provided the basis for development of the desired curves. These detriments has been computed for 1960, 1980, and 2010 conditions of water use and economic development and for salinity concentrations of 697, 876, and 990 mg/l. These nine points were utilized to develop detriment curves for 1960, 1980 and 2010. Straight-line interpolation was

Table 4. Direct and Indirect Penalty Costs
Lower Colorado River Basin and
Southern California Water Service Area

Type of Penalty Costs	Penalty Costs 1980 ($1,000 Annually)*	Penalty Costs 2010 ($1,000 Annually)*
Agrigultural		
Direct	5,713	12,741
Indirect	3,212	8,557
Total	8,925	21,298
Industrial		
Direct	163	513
Indirect	7	20
Total	170	533
Municipal		
Direct	1,622	3,018
Indirect	318	546
Total	1,940	3,564
Total Direct	7,498	16,272
Total Indirect	3,537	9,123
TOTAL	11,035	25,395

* 1960 Dollars

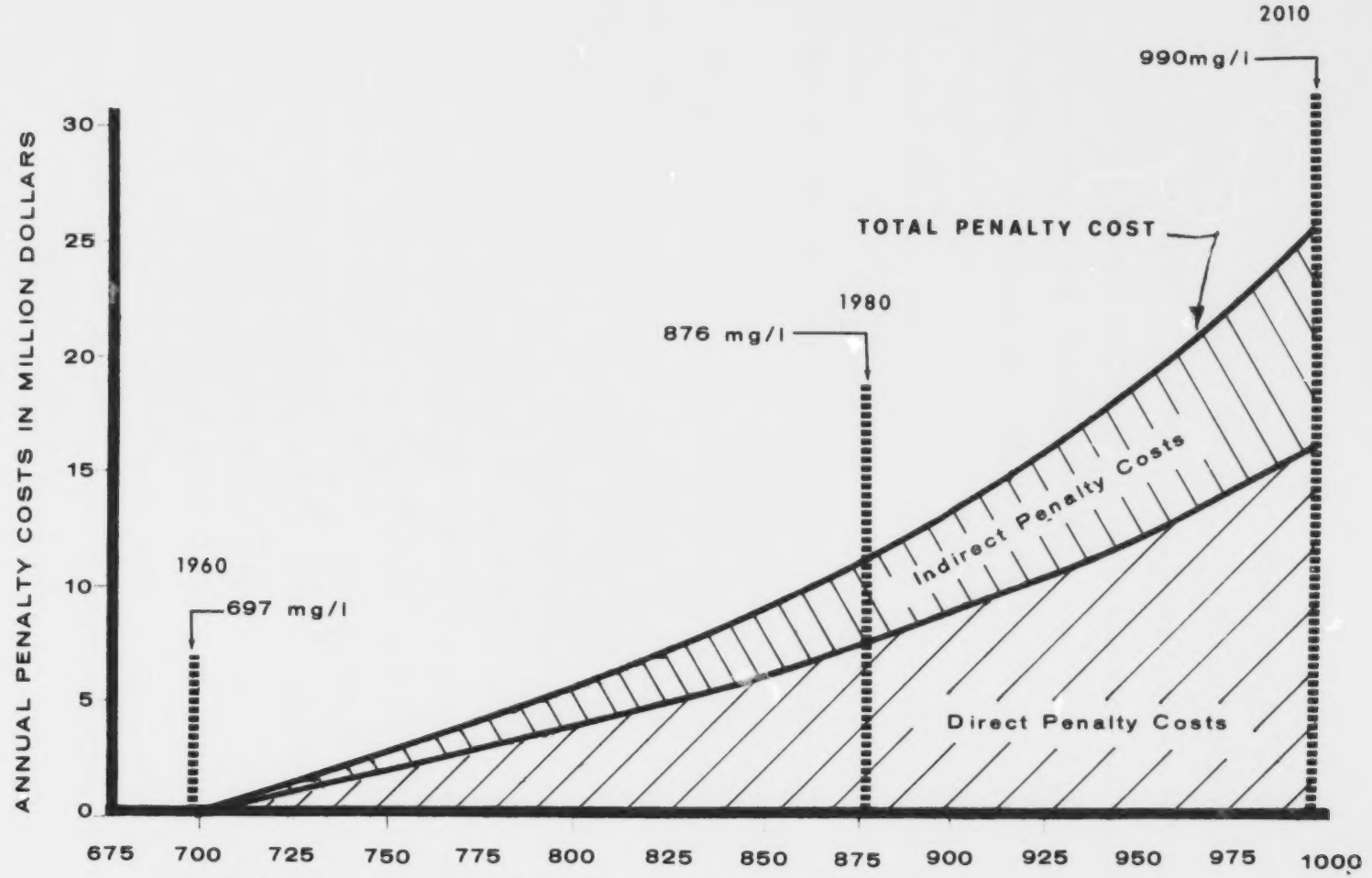

Figure 5. Direct & Indirect Penalty Costs Lower Colorado River Basin & California Water Service Area

utilized to develop curves for 1970, 1990, and 2000. The salinity range of the curves was then extended to the desired limits by extrapolation of indicated trends.

Direct penalty costs were computed at 10-year intervals from the newly developed curves using 1960 conditions of water use for base conditions. Indirect penalty costs were then derived from the direct penalty costs utilizing the assumptions that the ratios of indirect to direct costs computed from Table 4 for 1980 and 2010 conditions would hold over the full salinity range and that similar ratios for other years could be interpolated. The utilization of these assumptions eliminated substantial input-output analysis.

The summation of the indirect penalty costs derived in this manner and direct detriment costs resulted in the development of total detriment curves expressed in Terms of 1960 dollars. To update these curves to present conditions, they were adjusted for changes in the value of the dollar from 1960 to 1970.

One popular index of the average change in the purchasing power of the dollar is the Consumer Price Index. This index increased from 103 in 1960 to 131 in early 1970. (16) This change would indicate that a 1960 dollar was equivalent to 1.27 1970 dollars. The detriment curves were adjusted upward on this basis. The use of a single index was considered adequate for this adjustment since other appropriate indexes, such as the agricultural price index, which could be applied have increased in essentially the same proportions as the CPI.

The final total detriment curves which represent the total impact on the economy of using saline waters in terms of 1970 dollars are shown in Figure 6. These detriments curves can be utilized to determine the salinity control benefits that would accrue to a specific salinity control project. Such benefits are the differences in detriments associated with salinity concentrations which would occur with or without implementation of the control project.

Sensitivity Analysis.--To provide a basis for evaluating future salinity penalty costs, a detailed evaluation was made of present and future salinity levels at various points throughout the basin. The details of this evaluation are discussed in Appendix B. Such factors as the period of hydrological record and the rate of increase in consumptive use resulting from water resource development may produce significant variations in projections of future salinity levels. These variations in turn may affect predictions of the future economic impact of salinity increases. The sensitivity of salinity and economic projections to variations in mean annual virgin streamflow and future depletions of steamflow are discussed in this section.

The basic salinity projections utilized for the detailed economic analysis were based on the 1942-1961 period of record adjusted for 1960 conditions of water use. The mean annual virgin flow at Lees Ferry, Arizona, for this period was estimated to be 13.8 million acre-feet. (9) There is a probability of about 0.78 that this value will be exceeded by any 20-year mean virgin

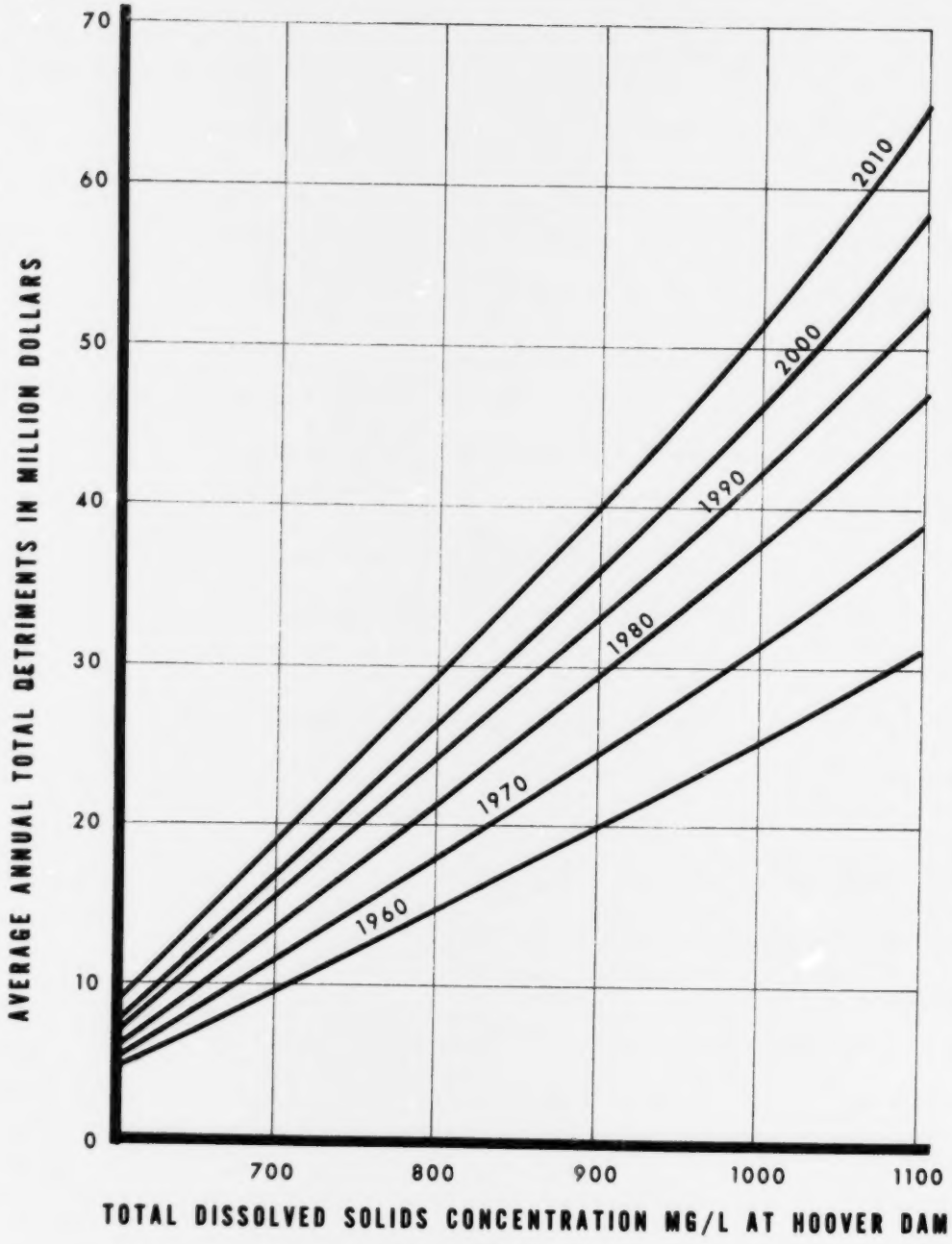

Figure 6. Salinity Detriments

flow.[17] The rationale behind selection of this period of record is summarized in Appendix B and will not be discussed here.

To test the sensitivity of salinity projections to variations in the base flow utilized in the analysis, three additional base flows with different probabilities of occurrence were evaluated. The flows evaluated were a 50-year mean flow with a probability of being exceeded of 0.50 and two 20-year mean flows with probabilities of being exceeded in 20-year period of 0.125 and 0.875.[17] These latter two flows are the upper and lower limits of a probable 75 percent of all 20-year mean flows. The virgin flow volumes for the four base flows evaluated are listed in Table 5. Salinity projections were made on the basis of identical present and future depletions of these virgin flows for all flow levels. Salt loads for the three additional base flows were estimated by adjusting the 1942-1961 mean salt load using the assumption that incremental changes in virgin flow would have a salinity concentration of 300 mg/l. This salinity concentration was selected from comparisons of salinity concentrations vs run-off relationship for low and high flow years.[9]

Table 5. Range of Virgin Flows at Lees Ferry

Designation	Virgin Flow (Million Acre-Feet)	Probability of Being Exceeded in a 20-year Period
Upper Limit	16.8	0.125
Mean Flow	15.4	0.500
Base Flow	13.8	0.780
Lower Limit	13.2	0.875

Projections of present and future salinity concentrations for the four base flows evaluated are shown in Figure 7. Projected

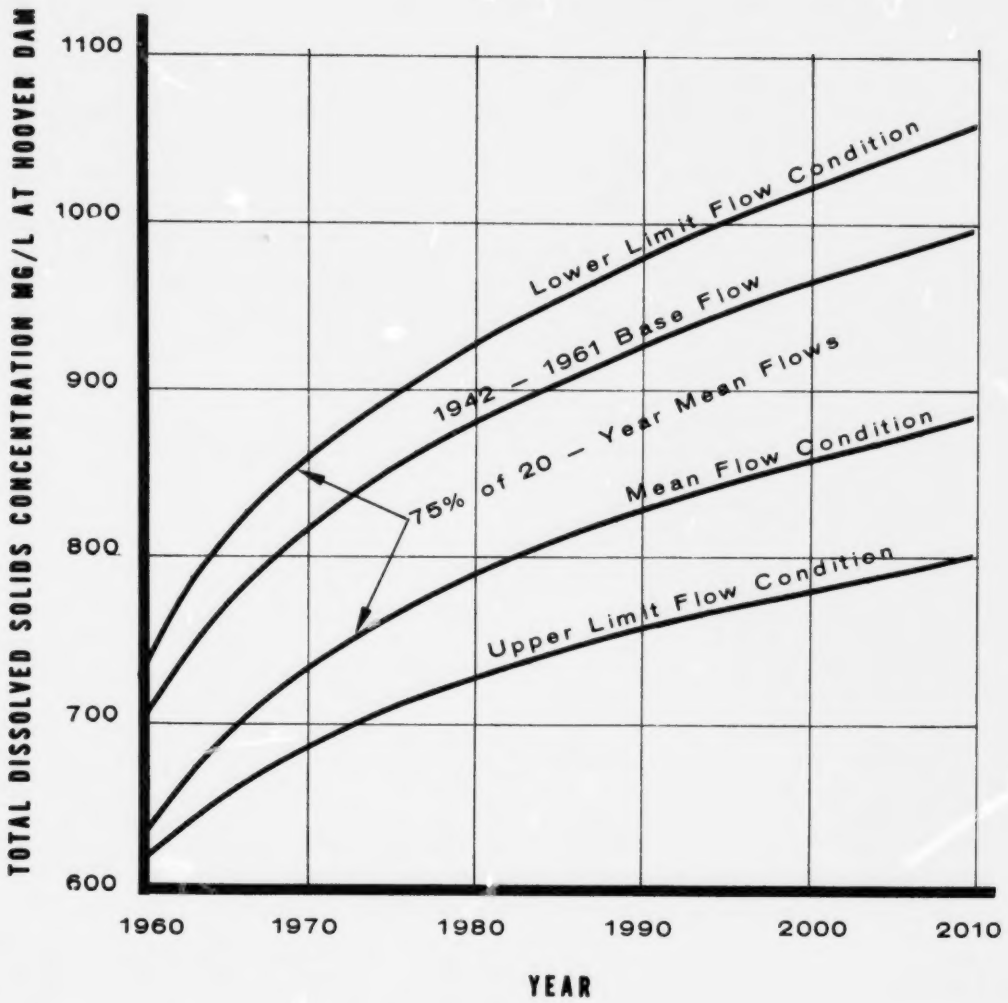

Figure 7. Sensitivity of Salinity Projections to Base Flow Variations

increases in salinity concentrations between 1960 and 2010 range from 180 to 330 mg/l. The basic analysis base flow of 13.8 million acre-feet predicted an increase of 293 mg/l.

The detriment curves in Figure 6 and the salinity projections in Figure 7 were utilized to formulate projections of future increases in salinity detriments. These projections are shown in Figure 8. Predicted increases in total annual detriments (total penalty costs) between 1960 and 2010 range from $23 million to $46 million. The basic analysis predicted an increase of $40 million. This wide range of predicted penalty costs indicates that the economic analysis is highly sensitive to variations in mean streamflow. However, the base analysis deviated only 20 percent from predicted changes under mean flow conditions. Selection of a more critical low-flow condition, a common practice in water pollution analysis, did not substantially alter the determination of penalty costs.

Considerable differences of opinion exist over the rate at which Upper Basin water resource development and increased depletion of streamflow will proceed. For the basic analysis, a depletion schedule based primarily on 1966 Bureau of Reclamation estimates was used.(18) Some authorities predict that development will proceed at a more rapid rate than the schedule selected. Actual development to date has been slightly slower due to fiscal constraints. If such constraints continue they could further delay future development. Three additional depletion schedules were evaluated to test the sensitivity of salinity and penalty cost projections to variations in depletions.

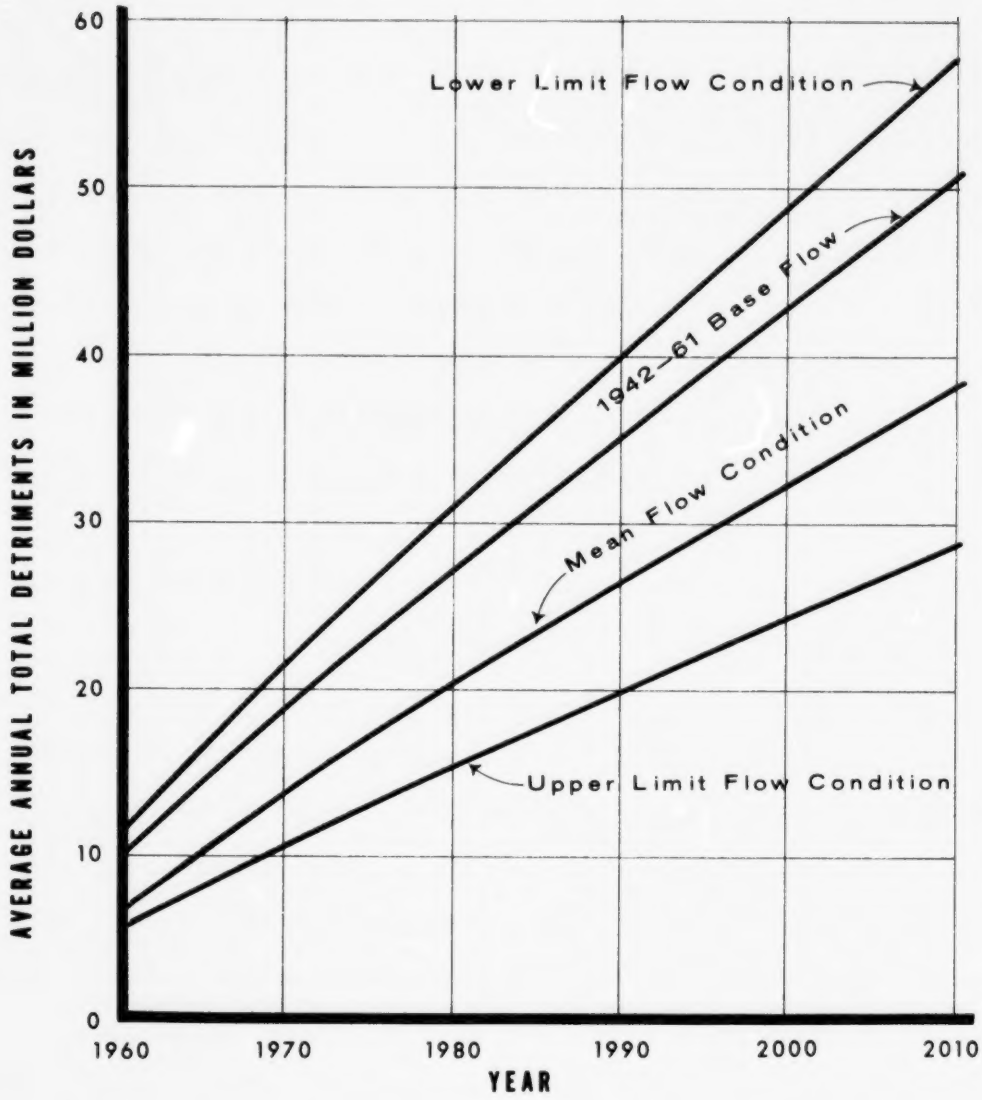

Figure 8. Sensitivity of Detriment Projections to Base Flow Variations

An accelerated schedule was utilized to evaluate optimistic projections, a mean schedule was utilized to represent, present trends and a reduced schedule was utilized to reflect possible future delays. Figure 9 and 10 present the salinity and detriment projections resulting from this sensitivity analysis. The smaller range between upper and lower limits on these projections would indicate a lower degree of sensitivity than that exhibited by variations in base flow. The convergence of the accelerated depletion and base analysis curves is the result of constraints imposed by the Colorado River Compact on maximum depletions.

Salinity Management Costs

If salinity concentrations are reduced by the implementation of control measures, certain costs will be incurred. These costs are known as salinity management costs and are the second major component of total salinity costs. The form and magnitude of salinity management costs are dependent upon a number of factors including the control measures utilized, the degree of salinity control achieved, etc. In a previous section on alternative salinity control management programs, the phased implementation of a salt load reduction program was selected as the least cost alternative for achieving basinwide management of salinity. The probable costs and effects of this least cost alternative program were evaluated as a means of estimating salinity management costs and are discussed in their section.

Available information on the costs and effects of salinity control measures from the latest technical investigation, research

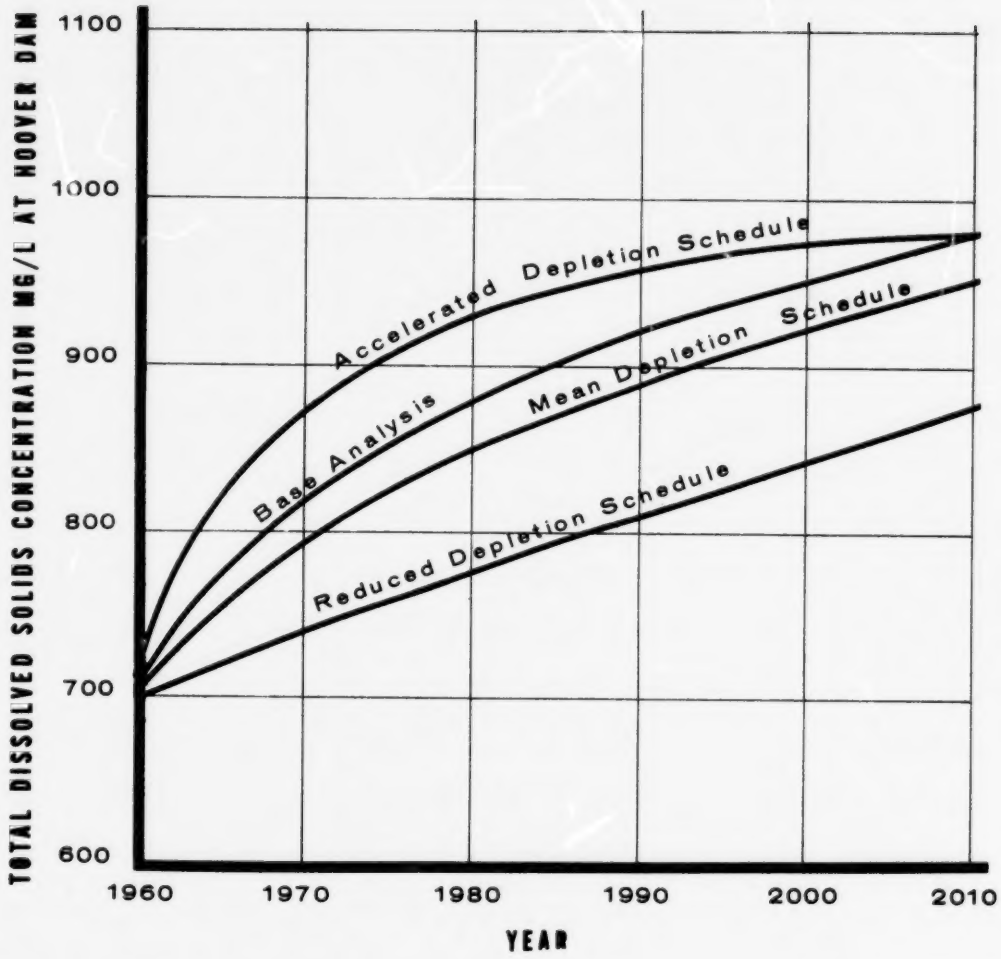

Figure 9. Sensitivity of Salinity Projections to Depletion Schedule Variations

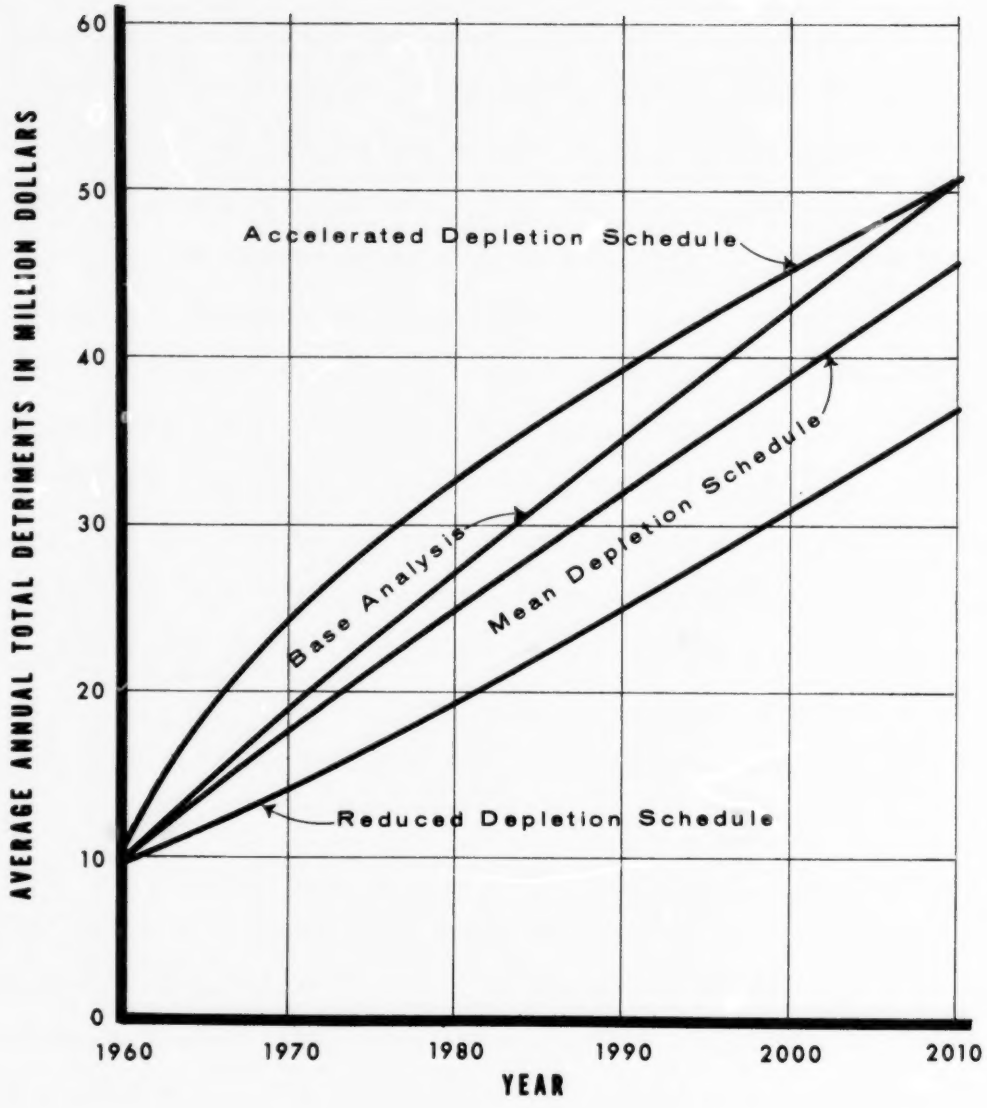

Figure 10. Sensitivity of Detriment Projections to Depletion Schedule Variations

and demnonstration activities was not sufficient to permit development of detailed estimates of project costs and salt-load reductions. To overcome this deficiency, Bayesian statistical decision theory, a statistical technique applicable to cases involving limited basic data, was utilized to provide estimates of the expected value of costs and salt load reduction for each individual project or irrigated area included in the selected program. Bayesian techniques differ from classical statistical techniques in that mean or expected values of a parameter may be derived by subjective assignment of probabilities of occurrence to each data point rather than by application of computational formulas to all data points in the classical manner. In cases of limited data, the appropriate application of Bayesian techniques may result in better estimates of the expected value of a parameter for a specific case than could be derived by averaging available data or extrapolating from one case to another.

The approach used to estimate costs and salt load reductions for each type of control measure differed slightly. For irrigation improvements, the costs of various types of improvements are relatively well defined. Two areas of uncertainty arise, however. The magnitude of improvements which a given irrigated area can economically support has not been evaluated. It was therefore necessary to estimate the range of improvements possible and the probability of each level of improvement occurring. Also, the average salt contribution of a given area was known but the extent

to which this salt load could be reduced by specific improvements has not yet been defined with certainty. Estimates of the possible range of salt load reductions and the probability of occurrence of each level of reduction were made based on recent research results and observed variations in annual salt contributions of the areas evaluated. The estimates of probable salt load reductions were also keyed to levels of improvement. A low level of salt load reduction was assigned to minimum improvements, a higher reduction to more extensive improvements, etc. In this manner, an upper and lower limit and an expected (mean) value of both salt load reductions and annual costs were derived for each irrigated area.

For the five salt load reduction projects formulated for control of natural sources, the magnitude of the salt loads to be controlled are relatively well defined. Since structural designs or geological site data were not available, however, detailed cost estimates could not be prepared. Thus, for these control projects, probable construction costs were the primary area of uncertainty. Possible ranges of costs were estimated and Bayesian techniques utilized as for the irrigation improvements to estimate upper and lower limits and expected values of salt load reductions and average annual costs.

The estimated expected values of both average annual costs and salt load reductions for the selected salt load reduction program are presented in Table 6. This table is an expansion of

Table 6. Salinity Management Project Date

	PROJECT DESCRIPTION		AVERAGE ANNUAL COSTS		EFFECTS AT HOOVER DAM				
No.	Location	Features	Total Proj. Cost ($1000)	Salinity Control Costs ($1000)	Flow Change (1000 AF/Yr)	Salt Load Reduction (1000 T/Yr)	TDS Reduction in mg/l 1980	TDS Reduction in mg/l 2010	Cost Index (S/T)
1	Paradox Valley, Colorado	Stream Diversion	700	700	0	180	15	16	3.89
2	Grand Valley, Colorado	Irrigation Improvement	3,140	1,570	38	312	29	33	5.04
3	Lower Stem Gunnison River, Colorado	Irrigation Improvement	3,600	1,800	45	334	32	35	5.40
4	Price River, Utah	Irrigation Improvement	1,000	500	13	89	9	9	5.65
5	Las Vegas Wash, Nevada	Export & Evaporation	600	600	- 10	100	7	8	6.00
6	Uncompahgre River, Colo.	Irrigation Improvement	4,000	2,000	50	320	31	35	6.25
7	Big Sandy Creek, Wyoming	Irrigation Improvement	490	245	7	39	4	4	6.28
8	La Verkin Springs, Utah	Impoundment & Evap.	600	600	- 7	80	6	6	7.50
9	Roaring Fork River, Colo.	Irrigation Improvement	880	440	13	52	6	6	8.47
10	Upper Stem Colorado River, Colorado	Irrigation Improvement	1,420	710	20	80	9	9	8.88
11	Henry's Fork River, Utah	Irrigation Improvement	710	355	- 10	40	4	5	8.88
12	Dirty Devil River, Utah	Irrigation Improvement	710	355	10	40	4	5	8.88
13	Duchesne River, Utah	Irrigation Improvement	5,660	2,830	65	273	29	32	10.37
14	San Rafael River, Utah	Irrigation Improvement	1,360	680	18	65	7	8	10.48
15	Ashley Creek, Utah	Irrigation Improvement	830	415	10	36	4	4	11.55
16	Glenwood Springs, Colo.	Desalination	5,000	5000	- 5	370	30	33	13.50
17	Blue Springs, Arizona	Export & Desalination	16,000	16,000	- 150	500	27	27	32.00
	Totals		46,700	34,800	127	2,910	253	275	--

Table 2 presented in a previous section of alternative salinity management programs. The physical features of the seventeen component projects are discussed in that section.

Two costs, total project costs and salinity control costs, are shown for each project in Table 6. These costs are in the form of average annual costs which include amortized construction, operation and maintenance costs. Total project costs, as the name indicates, consist of the total costs required to build, operate and maintain the specific project. Salinity control costs represent the portion of total costs allocated to salinity control. For the five single-purpose salt load reduction projects, all cost were allocated to salinity control. The irrigation improvements will produce other benefits of significant economic value in addition to salinity control benefits. Estimates of benefits produced by similar improvements which have been made by other agencies would indiciate that these benefits are of about the same economic value as salinity control benefits. Thus, allocation of costs in proportion to benefits resulted in assignment of onehalf of total irrigation improvement costs to salinity control.

Except for the Paradox Valley project, the various salinity control projects will produce a change in consumptive use of water. The entire flow from LaVerkin Springs and from Las Vegas Wash would be evaporated. For Glenwood Springs, the majority of the springs' discharge would be returned to the river system but some

consumptive use would result from disposal of brine. Control of Blue Springs would remove this discharge from the Colorado River system. The majority of the flow diverted would be available for consumptive use in central Arizona. The various irrigation improvements would result in water conservation. Reductions in consumptive use by phreatophytes, evaporation, etc. were estimated to average about one-half acre foot per irrigated acre when an entire irrigated area is improved. The estimated changes in flow at Hoover Dam for specific projects are shown in Table 6.

Utilizing the estimated changes in consumptive use and expected values of salt load reductions, the estimated reductions in average salinity concentrations at Hoover Dam were computed. Salinity reductions for each project for the years 1980 and 2010 are shown in Table 6. The effectiveness of a given salinity management project in reducing average salinity concentrations at Hoover Dam is dependent upon the volume and salinity of the average streamflow at Hoover Dam. Since future water resource development will reduce streamflow at Hoover Dam, a given salt-load reduction will produce a greater reduction in salinity concentrations in the future than a present. This fact is reflected in the differences between potential salinity reductions for 1980 and 2010.

The final parameter shown in Table 6 for each project is a cost index. This index is the ratio of average annual salinity

control costs to annual salt load reductions. The index is an indicator of the cost effectiveness of each project and was utilized to rank the projects in an order of increasing unit costs.

Utilizing the cost and salinity reduction data from Table 6, it was possible to construct a graph relating cumulative salinity management costs to cumulative reductions in salinity concentrations. Salinity management cost curves of this type for 1960, 1980, and 2010 conditions of water use are shown in Figure 11. By ranking projects in order of increasing unit costs, a curve that is concave upward results. The slope of the curve is related to the unit costs of salinity reduction.

In view of the elements of uncertainty that entered into the determination of the costs and salt load reductions of individual projects, it was desirable to test the sensitivity of the salinity management cost curve to variations in the costs and effects of individual project. This test was accomplished by plotting two additional salinity management cost curves utilizing the estimated upper and lower limits of costs and salt load reductions for each project. A comparison of the three curves for 1980 conditions of water use is shown in Figure 12. Although the range of possible costs and effects for a given project is large, the costs of achieving a given level of salinity reduction fall within a reasonable range for moderate levels of salinity control. This would indicate that cumulative salinity management costs have a relatively low sensitivity to errors in estimates for individual projects.

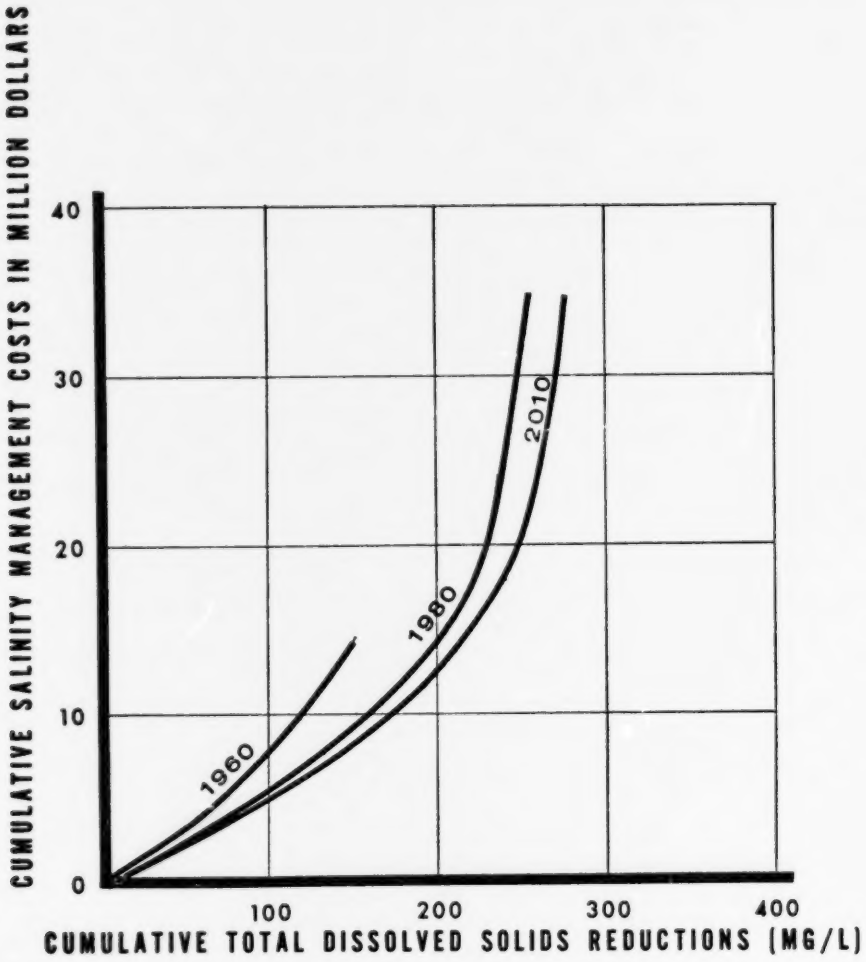

Figure 11. Salinity Management Costs

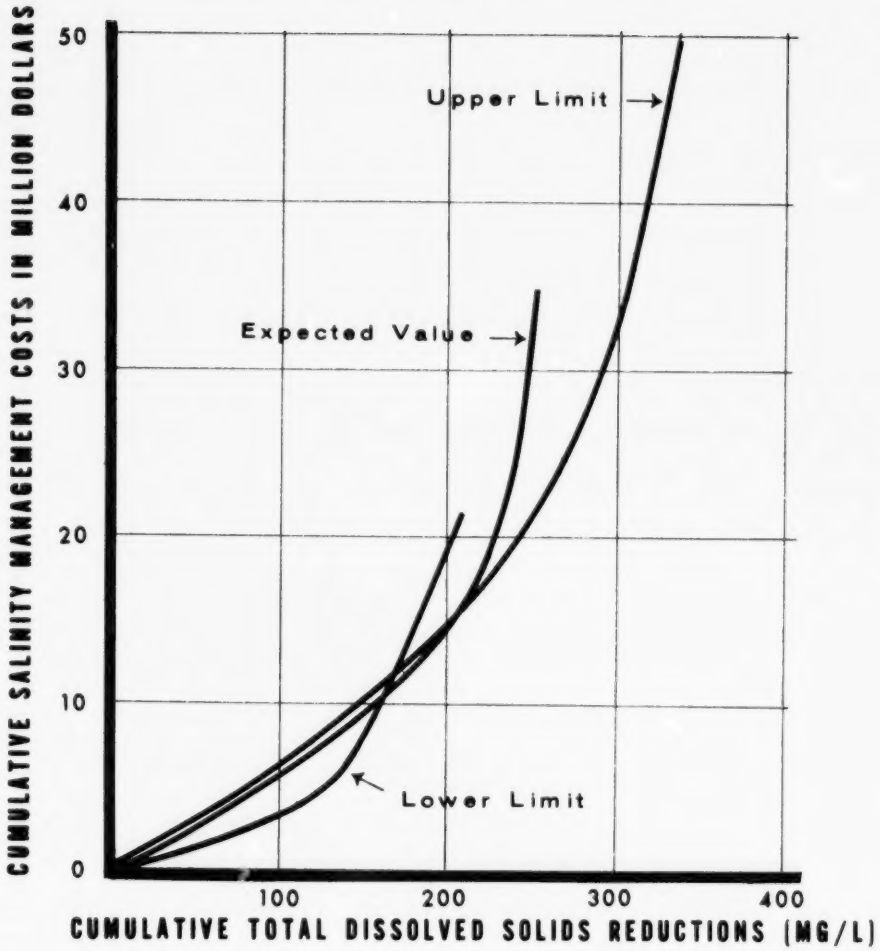

Figure 12. Salinity Management Cost Variations

Total Economic Impact

The total economic impact of salinity (total salinity costs) is the sum of salinity detriments plus salinity management costs. For a given salinity concentration and point in time, there are certain detriments associated with the use of water of that salinity and certain salinity management costs incurred in maintaining that salinity level. The sum of these two component costs is thus the total economic impact of salinity for the given time and salinity conditions.

Generalized total salinity cost curves can be developed by the proper manipulation and addition of the detriment curves presented in Figure 6 and the salinity management cost curve of Figure 11. An example of the determination of total salinity costs for 1980 conditions is shown in Figure 13. The 1980 detriment curve is identical to the one shown in Figure 6. Salinity concentrations at Hoover Dam are predicted to average 876 mg/l in 1980. This salinity level than becomes the origin of the salinity management cost curves. As salinity reductions increase, salinity concentrations decrease. The salinity management cost curve must therefore be plotted in the reverse direction of Figure 11 as shown on Figure 13. These two curves can then be summed vertically to yield the total cost curve.

In a similar manner, total cost curves were obtained for each decade from 1970 to 2010. These curves are shown in Figure 14. The component salinity detriment and salinity management

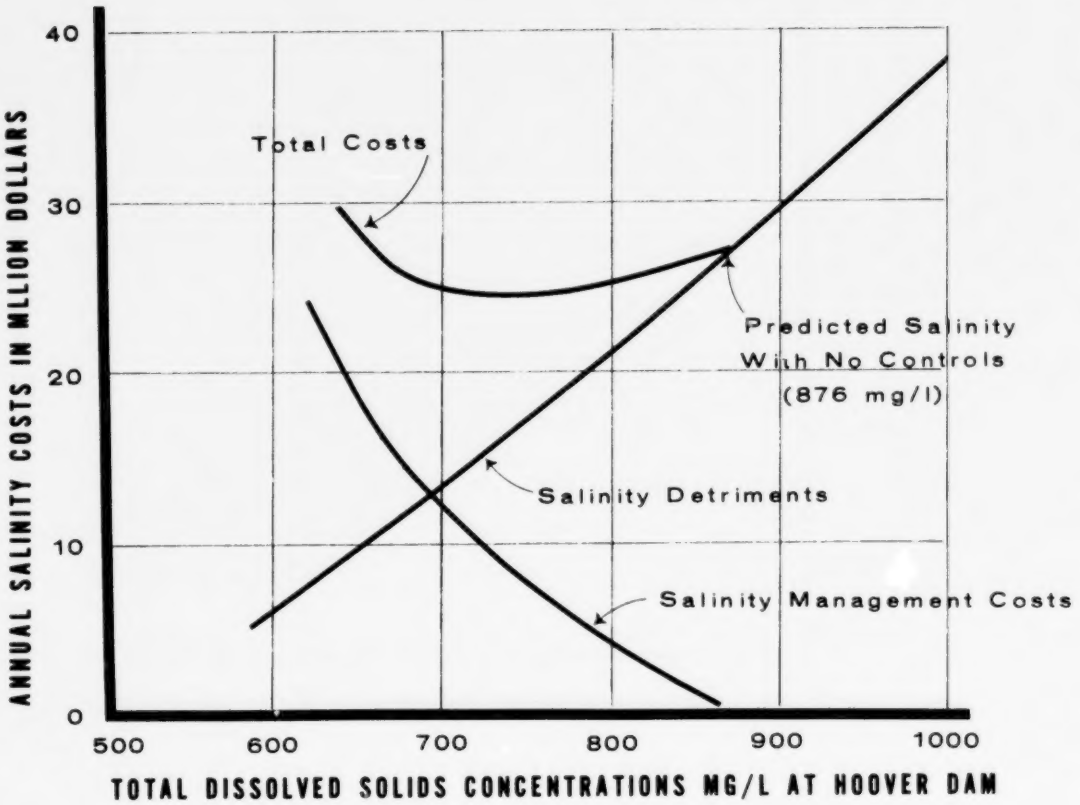

Figure 13. Determination of Total Salinity Costs (1980 Conditions)

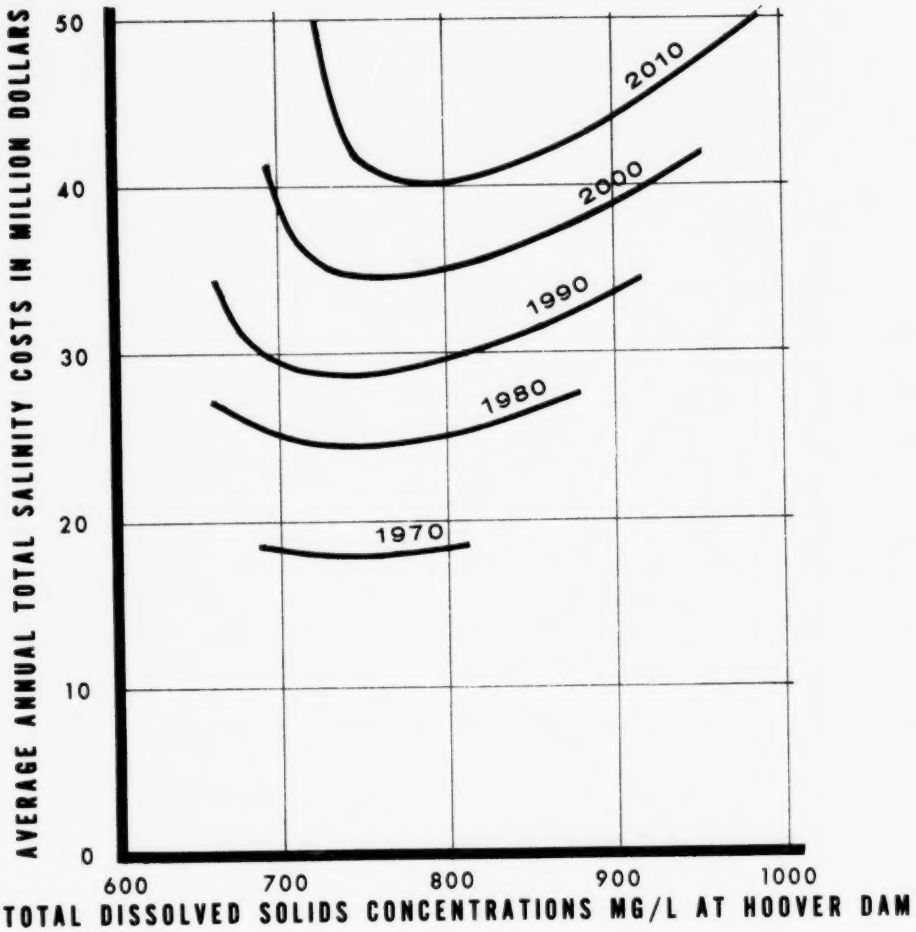

Figure 14. Total Salinity Costs

cost curves were not shown in this figure to avoid cluttering the drawing but may be obtained from Figure 6 and 11. It should be noted that the full lengths of the total cost curves are not shown in Figure 14 as the left end of each curve was truncated at a total cost equal to that at the right end of the curve. The segments of the curve shown were utilized for the evaluation alternative salinity management objectives discussed in the following section.

In view of the range of salinity management costs exhibited by the sensitivity analysis shown pictorially in Figure 12, it was desirable to check the sensitivity of the total cost curves to this range of management costs. The range of 1980 total costs obtained by using the three 1980 salinity management curves is shown in Figure 15. For 1980 conditions, total costs deviated only $\pm$ 10 percent from the expected value within the range of practical salinity management (700 to 876 mg/l). Salinity concentrations corresponding to minium total cost points varied less than 30 mg/l from the expected value. Similar results were obtained for other time periods. Total costs thus appear to be relatively insensitive to errors in deriving salinity management costs within the range of practical salinity management.

ECONOMIC AND WATER QUALITY EFFECTS

Salinity controls could be implemented to meet a variety of salinity management objectives which include both water quality and economic objectives. Since salinity levels and

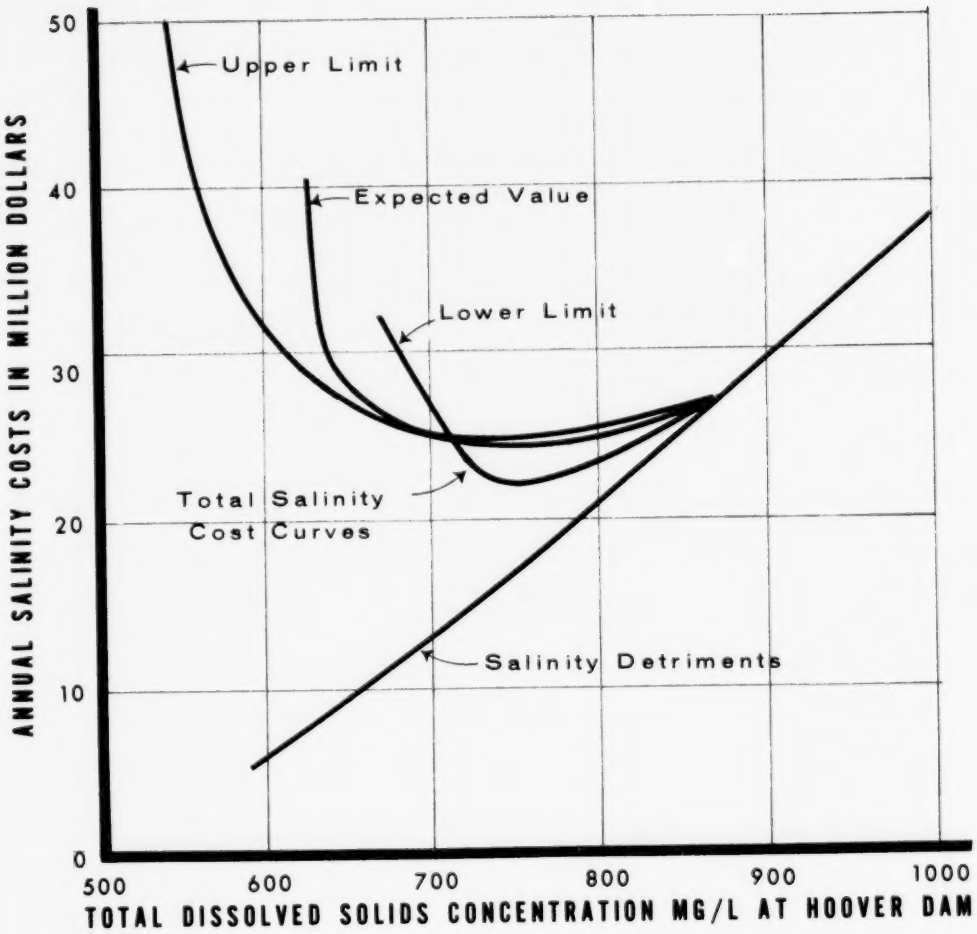

Figure 15. Total Salinity Cost Sensitivity Analysis
(1980 Conditions)

total salinity costs are interrelated, the selection of a water quality objective will result in the indirect selection of associated economic effects; conversely, the selection of an economic objective will result in the selection of associated salinity levels. A knowledge of the interrelationships between economic and water quality effects is thus useful in the rational selection of salinity management objectives.

By utilizing the total cost functions shown in Figure 7, the economic and water quality effects associated with three salinity management objectives were determined. The objectives evaluated were: (1) Maintain salinity at a level which minimize its total economic impact and achieve economic efficiency (minimum cost objective); (2) Maintain salinity concentrations at some specified level (constant salinity objective); and (3) Maintain salinity at some low level for which the total economic impact would be equal to the economic impact that would be produced if no action were taken at all (equal cost objective) A comparison of the economic and water quality effects associated with these three objectives, in the form of variations in salinity costs with time, are shown in Figure 16 for 1980 conditions of water use. The economic and water quality effects associated with allowing unlimited water resource development in the absence of salinity control works (no control approach) and associated with the limited development approach are shown in Figure 16.

In Figure 16, the right end of the total cost curve

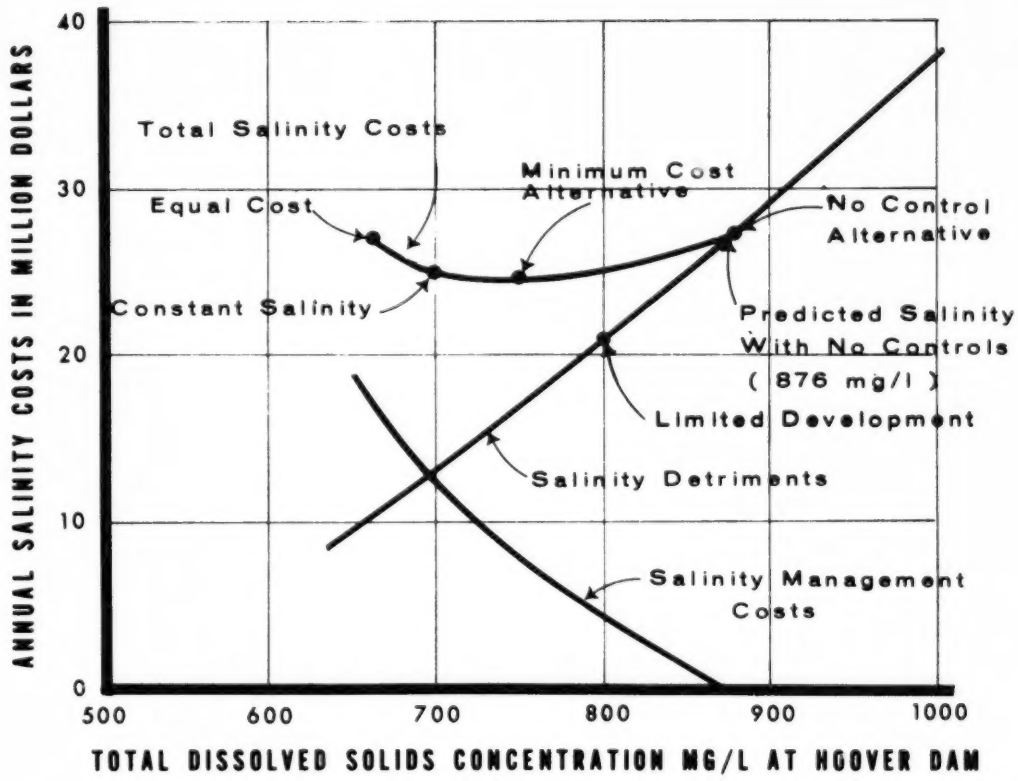

Figure 16. Comparison of Alternative Objectives (1980 Conditions)

corresponds to the projected salinity level at Hoover Dam if no controls are implemented (876 mg/l) and thus determines the total cost associated with the no control alternative. The salinity level associated with limited development intersects the salinity detriment curve to show that costs associated with the limited development alternative would be about $21 million annually and are obtained from salinity detriments alone. It should be noted that there are no control costs associated with the $21 million dollar total costs. In a very real sense, however, there are additional costs associated with this alternative in the form of benefits foregone. In fact, from Figure 16 one can observe that if benefits foregone exceed $4 million annually ($25 million - $21 million), this alternate would have total costs exceeding the total costs for alternates which include salinity control costs while allowing development to proceed beyond 1980.

All points on the total cost curve to the left of the no control point correspond to come level of salinity control. At the low point in the total cost curve, the total costs of salinity are at a minimum for the given conditions of water use and unconstrained development. Implementing salinity controls to reduce average salinity concentrations to this level would achieve the minimum cost objective.

At the left end of the total cost curve, total salinity costs are equal to total costs associated with the no control alternative. The left end of the curve thus corresponds to the equal cost alternative.

Total costs associated with a constant salinity objective are dependent upon the target salinity level selected and are determined by finding the intersection of the target level with the total cost curve. For this evaluation, a target salinity concentration of 700 mg/l was selected which corresponds closely to the average salinity level for 1960 conditions of water use.

The relative effects of the five alternatives were determined for other target years from Figure 14 in the same manner as shown by Figure 16. The economic effects associated with the five alternatives, in the form of variations in salinity costs with time, are shown in Figure 17.

Total salinity costs would be minimized by the limited development alternative but one must recognize the absence of cost associated with benefits foregone. If unrestricted water resource development is permitted, implementing salinity controls to achieve the minimim cost objective would minimize total salinity costs. The no control and equal cost alternatives produce the identical highest average costs and most rapid increase with time of all the alternatives evaluated. Total costs associated with a constant salinity objective will fall somewhere between the extremes established by the other alternatives with the exact cost dependent upon the target salinity level. For a target level of 700 mg/l, total costs approximate minimum costs until 1990, then increase rapidly, eventually exceeding the no control costs. Beyond the year 2000, the rapidly increasing costs reduce the practicality of maintaining this salinity level. Selection

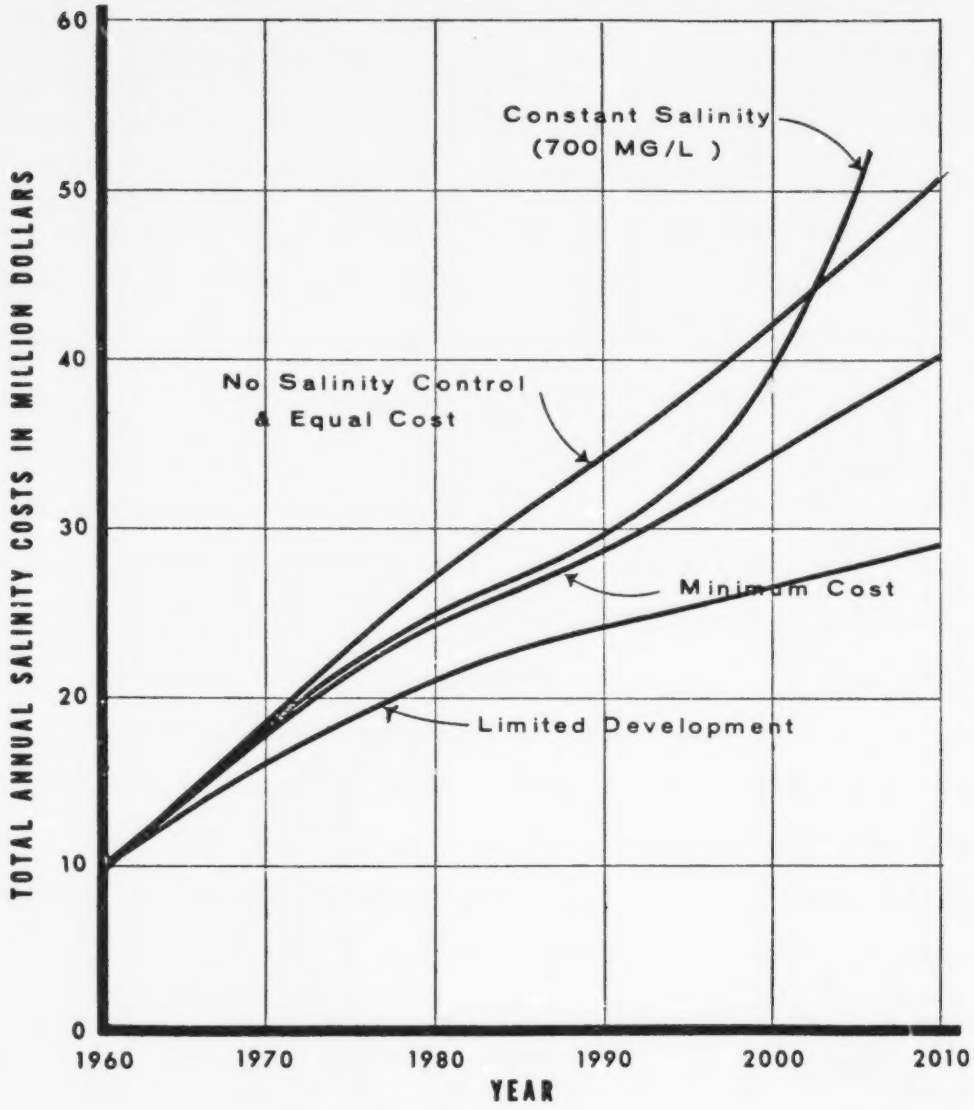

Figure 17. Salinity Costs vs Time

of a higher target salinity concentration for the years 2000 and 2010 would reduce the total cost of this alternative.

One important observation can be made from Figure 17. Regardless of the alternative selected, the future economic impact of salinity will be great. Although implementing salinity controls will result in the availability of better quality water for various uses and some of the economic impact will be shifted from salinity detriments to salinity management costs, the total economic impact of salinity will not be substantially reduced. As a minimum, average annual total salinity costs will increase threefold between 1960 and 2010. Selection of the limited development alternative would reduce total annual costs by only about 40 percent below the no control alternative in the year 2010.

Variations with time of the predicted salinity levels associated with the five alternatives evaluated are shown in Figure 18. With no controls implemented, average annual salinity concentrations at Hoover Dam are predicted to increase between 1960 and 2010 by about 42 percent or 293 mg/l. Selection of any of the other alternatives evaluated would substantially reduce future salinity concentrations below the no control levels. Except for the limited development alternative, these reductions would result in the maintenance of average salinity concentrations at or below present (1970) levels for more than 25 years. Resulting water quality therefore would be consistent with non-degradation provisions of the water quality standards adopted

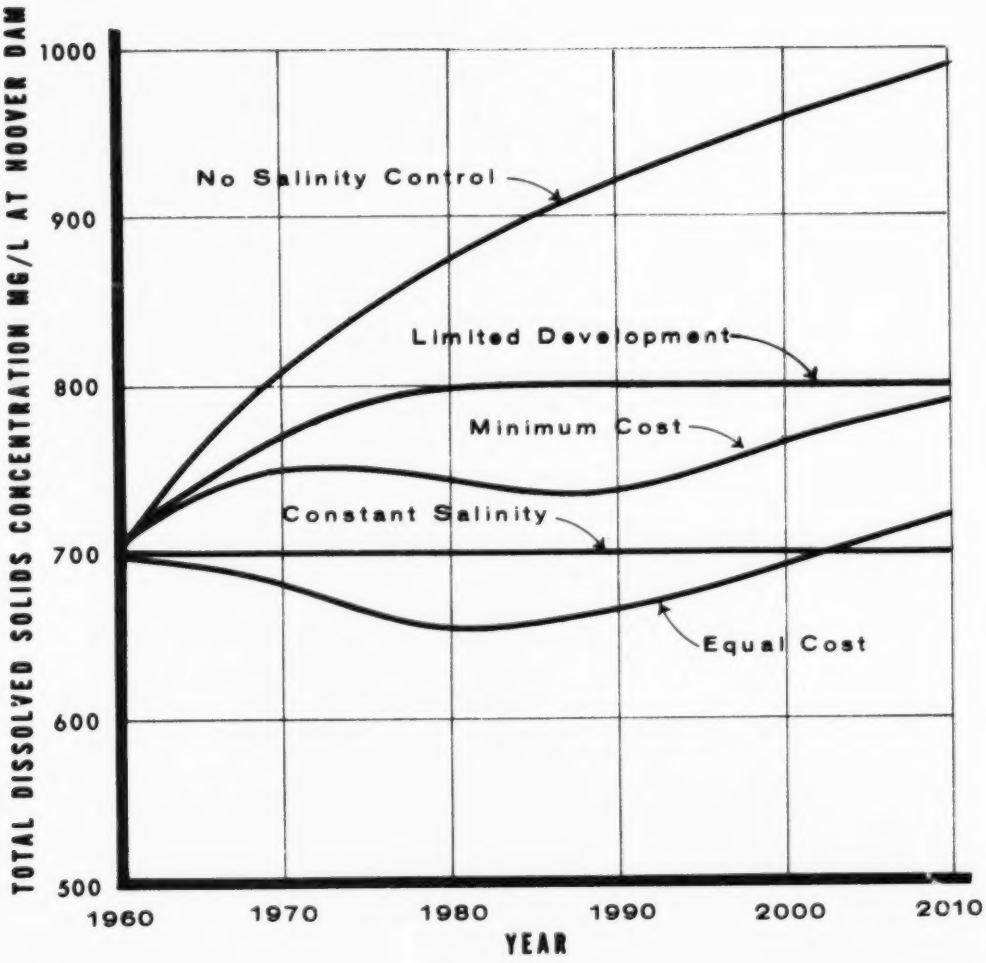

Figure 18. Salinity Concentration vs Time

Table 7 Comparison of Salinity Cost Distribution

Alternative Objective	Date	Salinity Detriments ($1,000/Yr)	Salinity Management Costs: Salt Load Reduction Projects ($1,000/Yr)	Salinity Management Costs: Salinity Control Costs ($1,000/Yr)	Salinity Management Costs: Total Salinity Management Costs ($1,000/Yr)	Total Salinity Costs ($1,000/Yr)
No Control	1980	27,700	0	0	0	27,700
	2010	50,500	0	0	0	50,500
Limited	1980	21,000	0	0	0	21,000
Development	2010	29,000	0	0	0	29,000
Minimum Cost	1980	17,000	1,300	5,900	7,200	24,200
	2010	28,500	1,900	10,800	12,700	41,200
Constant Salinity (700 mg/l)	1980	13,500	1,900	10,000	11,900	25,300
	2010	19,000	25,000	13,500	38,500	57,500
Equal Cost	1980	9,200	6,900	11,600	18,500	27,700
	2010	21,000	17,600	11,900	29,500	50,500

by the seven Basin States. The limited development alternative would result in slight increases in average salinity concentrations.

COST DISTRIBUTIONS AND EQUITY CONSIDERATIONS

Although the total economic impact of salinity associated with each of the alternatives evaluated varies over a limited range, the distribution of salinity costs related to each alternative differs greatly. Distribution of costs may therefore be an important factor in the selection of alternatives. Associated with cost distributions are various equity considerations. These, too, influence the selection of alternatives. Salinity cost distributions for the five alternatives evaluated for both 1980 and 2010 conditions of water use are compared in Table 7. A further breakdown of salinity management costs, by individual projects, is shown in Table 6.

The no control and equal cost alternatives produced the extremes in the range of cost distributions evaluated. Total costs for these two alternatives, by definition, are equal but the distributions of costs are vastly different. For the no control alternative, all costs are in the form of detriments. For the equal cost alternative, however, salinity detriments are reduced by an average of 60 percent. This cost reduction is offset by a corresponding increase in salinity management costs.

The extremes in the range of cost distribution point out the basis for equity considerations which may enter into the selection of management objectives. If the no control alternative is selected, all salinity costs would essentially be borne by water users and by the regional economy in the Lower Basin and southern California water service area. In contrast, selection of the equal cost alternative would redistribute a majority of the costs to investments in salinity control facilities in the drainage area upstream from Hoover Dam. Much of this investment would be for irrigation improvements in the Upper Basin, improvements that would produce substantial economic benefits in addition to salinity control benefits. The equity of these two extremes in cost distributions is vastly different.

Salinity detriments for the other three alternatives evaluated fall between the extremes established by the no control and equal cost alternatives. Salinity management costs are less than for the equal cost alternative. The equity of these cost distributions may also be an important factor in selection of the most desirable alternative. The cost distribution shown in Table 7 can be used to evaluate the relative costs and benefits of a given alternative. For example, a salinity control program designed to meet the minimum cost objective would have an estimated average annual cost of $7.2 million in 1980 and $12.7 million in 2010. The benefits associated with a given alternative would be the difference between salinity detriments expected if no controls are implemented and if the control program associated with that

alternative is implemented. For the minimum cost alternative, average annual salinity control benefits would total $10.7 million in 1980 and $22.0 million in 2010.

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